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JOURNAL

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JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 39.	1907.	No. 184.

Proceedings of the Four Hundred and Fifty-fifth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 21, 1907, Dr. R. T. GLAZEBROOK, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on Thursday, March 14, 1907, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

William Elsdon Dew.
Louis J. Hunt.
W. D. Kilroy.
Howard Marryat.
David K. Morris.
Henry H. Perry.
Arthur H. Seabrook.

From the class of Associates to that of Associate Members :—

James Coxon.
P. R. Friedlaender.
H. C. C. C. Silver
C. K. Stretch.
Edwin Thornton.

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From the class of Students to that of Associate Members :—

F. Heppenstall.	Bruce G. Rae.
W. F. Mylan.	W. H. Taylor.

C. F. Waddington.

The PRESIDENT: I have the sad duty to perform of calling the attention of the Institution to the great loss which all the members of our profession have sustained by the death of our Foreign Member, M. Hospitalier. All of us, I suppose, are well acquainted with many of his works, and many of us remember the evening that he gave to us some three years ago in this room when he explained to us the Ondograph. The Council at their meeting to-day unanimously recorded a vote of condolence with Madame Hospitalier, expressing the profound sympathy of the Council and members of the Institution with her and the other members of his family in their bereavement.

I have also to announce that the Council at their meeting to-day unanimously agreed to elect as an Honorary Member of the Institution Professor J. J. Thomson, who gave us such an admirable lecture a few weeks ago.

The following paper was read and discussed :—

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RAIL CORRUGATION.

By JOSEPH A. PANTON, Associate Member.

Paper read March 21, 1907.)

Introduction.—The question of rail corrugation has, until recently, been surrounded with a great deal of mystery, and has presented one of the most puzzling problems with which the traction engineer has been called upon to deal. Even at the present time great diversity of opinion still exists as to its real cause. It is because generalisation has been attempted without careful and detailed investigation that so much of a misleading character has been published on the subject. In the present paper the author proposes to deal with the subject in a general way, confining himself as briefly as possible to the practical side of the corrugation problem, without entering to any extent into the question of materials and methods of manufacture. Details will be given of the method employed by the author in investigating the corrugation problem, and of the results which have led him to adopt his present theory, special attention being paid to some of the latest developments, which it is hoped will prove of interest to members of this Institution. In dealing with a subject of such fundamental importance, it becomes necessary to consider certain points which, though familiar to all, would, from their very nature and bearing on the subject, leave the treatment incomplete if omitted. Little actual work has been done in connection with the subject under consideration, therefore few practical details are available. Recent experiments carried out with rail grinders have turned out more or less unsuccessful.

Rail Grinding.—At present, as a partial remedy the practice of grinding rails—and money—away is continued without making headway towards finding the actual cause of the trouble. Rail grinding can be accomplished by fixing to the car or locomotive a combined letter press and slipper block fitted with a refill carborundum shoe (see Fig. 1). It will be noticed that there are four carborundum blocks 6 in. × 3 in. × 3 in., fitted in the shoe. This arrangement is by no means the best, as when a grinder of this length is riding on the crest of a wave, the outer ends have a tendency to dip into the hollows. To obviate this one continuous block of carborundum would be preferable, in order to gain rigidity when negotiating waves of the same length. The author finds that a coarse grit of carborundum (No. 16) used on a wet day, with a medium file-cutting pressure, gives the best

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results. As regards wear of the carborundum blocks and power required to drive them, Figs. 1 and 2 (Fig. 2 illustrates shavings obtained with the grinder) clearly indicate in a general way what can be done in the way of a temporary expedient. Rail grinding is, however, by no means a remedy, as the corrugations soon reappear, which indicates that the cause of the trouble is to be sought in the equipment directly or indirectly in contact with the rails, and not in the rails themselves.

Rails.—Seeing that the actual corrugations occur on the rail, it is but natural to suppose that their presence or absence depends on the quality of the rail. The author has given careful consideration to this view, and has come to the conclusion that no satisfactory evidence has yet been put forward in support of it. In fact, enough evidence has now accumulated to contradict any rail theory that might be promulgated. It is therefore necessary to look elsewhere for a solution of this problem. In this connection the author would give the following amongst other reasons why the rail theory fails to account for the presence of corrugation:—

1. Because rails manufactured by every firm in the world have corrugated since the advent of electric traction.
2. That the rails did not corrugate in the days of horse and steam cars.
3. That the check rails are corrugated to an equal degree, the corrugations being parallel to those on the crown of the rail.
4. That rails did not corrugate so long as the armatures were built on the axle.
5. That it takes on the average three years to develop corrugations on a new system, and only three weeks on relaying with new rails thereafter.
6. That an ordinary railway rail taken from the straight road of an electrically operated railway (where no corrugations occur) and relaid on a checked curve soon corrugates.

These are a few of the principal reasons showing that the blame cannot be attributed to the rails or to their manufacturers. Further, corrugated rails have been tested and found to contain all the chemical constituents and to possess the physical qualities required of them. It has been said, and continues to be repeated, that the trouble is due to the chattering of the rolls of the rolling mills, owing to play in the pinions and bearings of the rolls driven by antiquated steam engines. Such statements are misleading and without foundation. For the sake of argument assume that the chattering of the roll does corrugate the rails. Why, then, is it that the rails on electrically operated railways only corrugate on checked curves, the remaining seven-eighths of the track being perfect? And why does it take so long to corrugate tramway rails on a new system, and so short a time on renewals? And why are not corrugations found on steam railroads, running at 60 miles per hour? These are facts which one cannot

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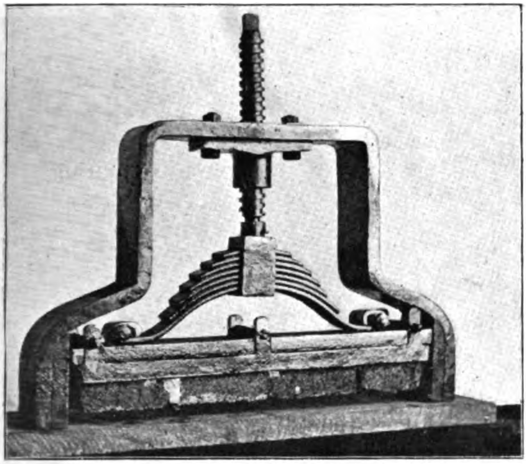

FIG. 1.—24-in. Rail Grinder.

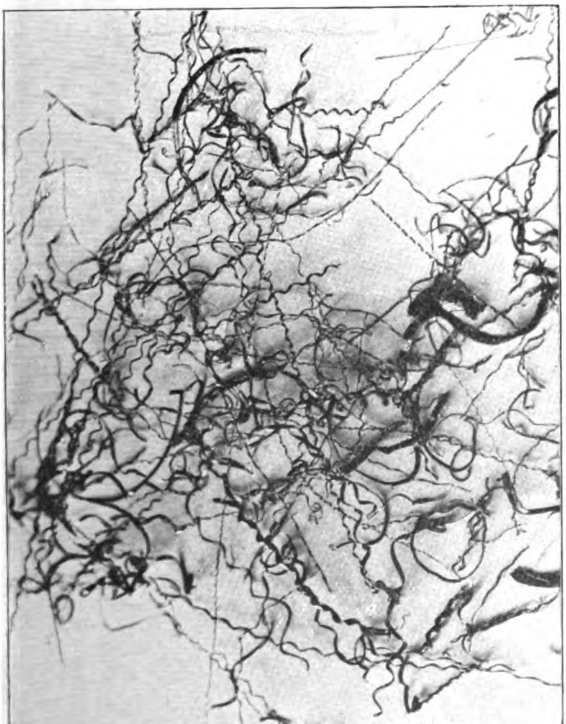

FIG. 2.

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get away from, and they entirely dispose of the rolling theory. Further, in this country and abroad, corrugations 24 ins. to 30 ins. in wave-length are to be found. If chattering is going on in the Middlesbrough rolling mills on so gigantic a scale, the noise of it should be audible for miles around.

Defective Railway Rolling Stock.—The author's attention was first drawn to defects in rolling stock as a means whereby corrugation might be caused about three years ago, by the action of a flanged brake block then being tried to keep down wheel flanges. The tendency of the flanged brake blocks was to cut into the outer edge of the wheel tire as here shown (Fig. 3), and it appeared difficult to account for this peculiar action. Later on it occurred to the author that the bogie truck frame and the wheels were not acting in unison, especially when rounding sharp curves. The bogie truck frame, by means of the hangers, communicated to the brake block a twisting movement, that is to say, the truck frame and brake block had a tendency to get out of line with the wheels when on the curve, but were being prevented by the flange of the brake block ; hence the thrust on the said brake block

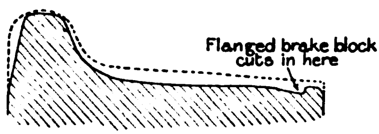

FIG. 3.

and its tendency to cut the wheel tread. On reverting to the brake block without a flange no cutting of the wheel-tread occurred. Having got thus far, by judicious watching it soon became apparent that this brake block had a decided tendency to run off the wheel tread on one side and cut into the flange on the other, as here represented (Fig. 4). On further examination it was soon found that the frames were out of square and the axles out of line or oblique to the line of motion, as already stated, this being due probably to the axle being geared at one end of the shaft only, the tendency being to form diamond-shaped truck frames. To prove this remarkable result of defective gearing the author has only to draw attention to the case of the Liverpool Overhead Railway during the first nine or ten years of its existence, when the armatures were built on the axle, whereby a symmetrical drive was obtained. During this period there was no sign of any corrugations. On introducing single-ended geared axles into the same bogies, a series of difficulties cropped up when running over the same rails, necessitating the renewal of rails on checked curves—a serious additional expense. If, in the light of this result, the fact is considered that at least 75 per cent. of the present-day electric railway and tramway equipments are unsuitably mounted on trucks of weak foreign design, the main feature of which is lack of durability, due to cheap methods of production, the outlook is anything but hopeful.

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Defective Tramway Rolling Stock.—Many similar cases have occurred on tramway undertakings where the conversion from steam to electric traction over the same rails has brought about corrugation. The tendency of a gear is to get away from the pinion, and it can do so in time, due to the wear of the motor brasses, axle sleeve brasses, horn slides, etc. Being geared at one end and mounted in a weak truck frame, the whole tendency is to push the frame out of square and the axles out of the line, and, as an examination of the wheel tyres clearly indicates, a grinding action takes place between the wheel flanges and guard rails. The wheels soon become groove-locked when speed is attained, and the wheel flanges striking the check rail intermittently cause the whole axle to jump or oscillate in the groove, giving rise to intermittent skidding and producing the peculiar flattening of the rail known as corrugation. Corrugations will also be found on the check rail, equal and parallel to those on the crown of the rail, which clearly demonstrates that the wheels oscillate in the groove. This soon brings

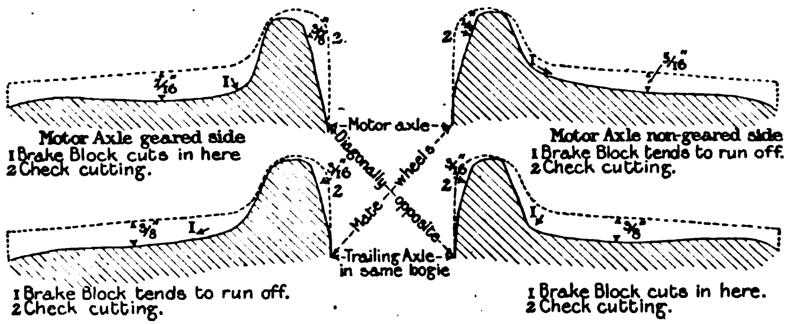

FIG. 4.—Tyres of Single Motor Bogie Truck.

about unequal tires on the same axle, causing a momentary slowing or lagging behind of one tire, which still further increases the tendency of wheel tires to lock, as can readily be seen by the severe indentations on the check rail, each indentation tapering off to nothing as the tire is freed. Immediately the tire is freed it jumps forward the required distance to bring it into line, producing a sort of case-hardening effect on the head of the rail which remains high, and as it is at the same time revolving, in doing so it scoops or grinds intermittent hollows in the rails, the wave-lengths being determined by the speed and elasticity of the track. In the matter of wheels old practices have been retained longer than might have been expected, and longer than would have been the case had not first cost been a factor that had to be considered. The multitude of flange shapes and treads that existed in the horse-car days are still in existence, few changes having been made in their dimensions or contour, a matter which requires immediate attention; for as the speed and weight of cars have been considerably increased the tread and wheel flanges

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ought to be suitably modified to adapt them to the new conditions. Again, the running of a ¾-in. thick flange in a 1-in. wide groove requires further consideration, especially when rounding curves.

Excessive Wheel and Flange Wear.—It would be safe to assume that 75 per cent. of our electric railways and tramways are troubled more or less with excessive and irregular flange and tread wear of their wheels. In the case of bogie trucks sharp flanges are produced on wheels in diagonally opposite corners of the truck, and square flanges on the mate wheels (see Fig. 4). This peculiarity has developed greatly since the advent of electric traction, and clearly indicates to the author's mind that the method of single-ended gear-driven axles has the tendency to send the geared end of the axle forward, while the mate wheel has the reverse tendency; hence the sharp flange on the wheel nearest the gear, which, being the aggressor, is found to be of smaller circumference than the mate wheel, as shown in Fig. 4. The slightest difference in circumference of two wheels on the same axle will throw additional weight and wear on the smaller or slow wheel; the author has repeatedly measured differences in circumferences varying from ¾ in. to 1 in. The slow wheel therefore grinds the

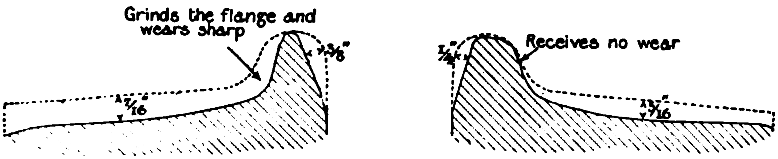

FIG. 5.—Typical Example of Trailing Coach Tyres.

flange and causes it to wear sharp (see Fig. 5), while the flange of the mate wheel is drawn away from contact with the rail and receives no wear. This results in an unbalanced condition of the car body, especially when rounding curves, which throws undue and constant pressure on the smaller wheels. In the case of street cars, where there is no elevation on curves, the inequalities of wheel circumferences are further aggravated. It will also be found that in short wheel base trucks secured to the car body the two smaller wheels will be on the same side of the car, thus making an unbalanced condition of the car whether running on the straight or curved track. On one side the wheels are cut into at the back of the flanges, whilst on the other side the tires are frilled over the rim, which will tend to increase further the corrugations where unequal rail level of the track exists. In serious cases this unbalanced condition has caused a cant or tilt of the car body representing ⅞ in. in 9 ft. 6 ins. This accounts for the varying conditions of corrugations so often found on the straight track. The type of truck known as "Brill E. 21" cannot get out of square so easily, but the axles still get skewed, though remaining parallel to each other. Taking into consideration the direction of motion, the accompanying diagram (Fig. 6) will illustrate why the two smaller wheels come to be

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on the same side of the car. Speaking generally, corrugations are most likely to be found in towns and cities where sharp loops and curves are negotiated regardless of speed with top-heavy canopy-covered cars and trucks that were never designed for such circumstances, consisting of a few stampings and castings bolted together regardless of accurate fitting. Such frames are unable to retain their original squareness, however well reinforced with corner plates. This lack of squareness means axles out of parallel, motors out of alignment, and bearings out of truth, resulting in climbing wheels, hot boxes, unnecessary consumption of power, and rapid deterioration of rolling stock and rails. Some twelve months ago a set of Corporation tramway trucks were put through the engineering shops, thoroughly squared up, planed, fitted, and finished. These trucks were then put on a particular route, and it is very gratifying to hear that the wheel flanges are greatly improved

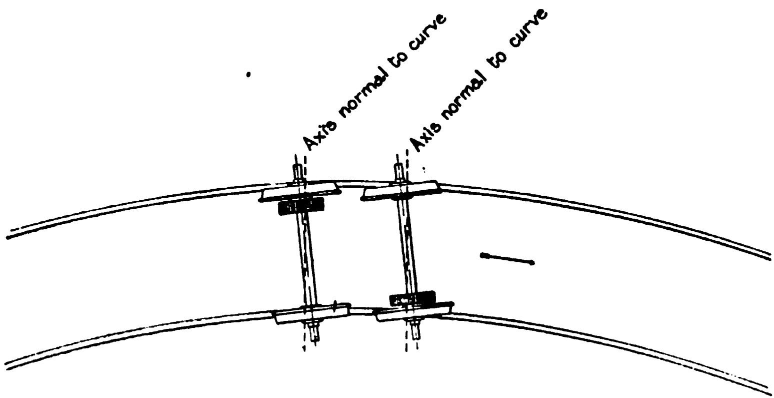

FIG. 6.—Parallel Skewed Axles.

and the corrugations reduced to one-half their original size. The author has also taken in the side frames of a Brill E. 21 truck 1 in., still finding the same bolt holes in the car body; the result is a much steadier running car with better wheel flanges. One therefore arrives at the result that corrugations on electric railways and tramways are caused by weak bogie frames and trucks, unable to withstand the side strains of top-heavy cars running at high speed on flat curves of short radii, the weakness being intensified by unsymmetrically driven axles being run through sharp loops and turnouts. Hence in towns where corrugations do not appear, a perfect track will be found with trucks of sound mechanical design, preferably "former" built under refined engineering conditions. Recent trucks have been designed to permit of the wheels and axles moving laterally upon curves, but how much lateral play can be expected with a ¾-in. flange running in a 1-in. groove, admitting inequalities in track gauge?

Check Cutting.—This is one more instance of skewed axles and

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unequal tires on the same axle, resulting in the wearing away of the back of the wheel flanges as seen in Figs. 4 and 5, representing something like $\frac{1}{4}$ to $\frac{3}{8}$ in. More serious still, however, is the wearing away of the check rails, necessitating the renewal of checks every twelve to eighteen months. Not only so, but the swarf or filings given off have a tendency (as will be readily understood) to get into the motors and bearings, causing further complications. The author finds that check cutting is not due to want of lubrication between the coach and bolster of the bogie, as at first seemed apparent, but rather to the oblique running of the wheels and axles, especially with tires of different diameter on the same axle. This leads to another important subject, namely:—

Broken Axles.—Taking the case of axles which are not deficient in material and construction, the author has observed that these fractures occur on the geared side of the axle, where the shaft enters the hub of

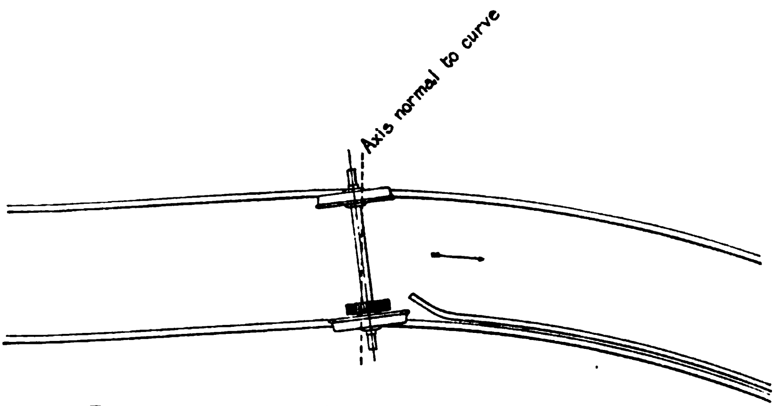

FIG. 7.—Unsymmetrically Driven Axle striking Check Rail.

the wheel. A fractured axle appears to be short in the grain, as if all the nature had gone out of the steel. Samples of this material have been tested, and the tensile strength and ductility have been found to be up to the standard. On examination, however, it will be noticed that the complete break is composed of a series of short fractures, evidently caused at different times and places, round the outer circumference of the shaft, which cannot be observed outwardly with the eye or lens. The author is strongly of opinion that these fractures are caused by the skewed axles coming up to the curve at the wrong angle, as shown in Fig. 7, this occurring when the axle is rigidly held in position by the motor on the geared side. With such a deviation it is quite obvious that the flange of the wheel (especially the wheel nearest the gear) strikes the check rail violently on entering the curve, the blow being determined by the horse-power of the motor, speed, weight of the train or car, and leverage from wheel flange to axle shaft.

This leverage is also responsible for broken spokes in solid cast

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wheel centres of motor axles. This skewing of axles is quite apparent on short chain curves, the check rail showing a decided cutting away of the ramped part of the check as the wheel enters the curve. It therefore appears that the only hope of saving axles at the present time is to keep the power switched off the motors as far as possible when rounding curves, so that the axles can move freely to suit the circumstances.

Roaring Rails.—Roaring rails are found principally on Indian steam railroads, and, reviewing the evidence from that direction, it can only be surmised that the trouble originates in much the same way as corrugation, namely, from defects in the rolling stock, such as excessive play at the journals or longitudinal play between the journal box and pedestal, which would in time, by constant hammering, cause the sides of the truck frame to spread outwardly, at the same time distorting other parts of the frame connected therewith. Such faulty truck design allows the centrifugal forces to centre at various points in the truck, thereby shifting the centre of gravity horizontally and causing unequal strains on the wheel flanges and unequal tires on the same axle. Consider a truck of this description when rounding a curve. The centrifugal forces acting on the vehicle and truck frame, the kinetic energy is being dissipated in taking up the play between the journal box and pedestal; the wheels and axles remain unsuited to the curve, the available momentum not being sufficient to carry them to the high side of the curve. This is more apparent on electric railroads by reason of the extra weight of motors on the axles, and consequent friction between wheel and rail—a further reason towards the early development of corrugation as compared with steam and cable railroads. (The above action of vehicles when rounding curves has already been confirmed with reference to flanged brake blocks.) The outer wheels must therefore lag and skid round the curve like the oar of a rowing boat. Wheels of different circumferences are formed, the two smaller wheels being on the same side of the truck, especially when trains or cars are run on the same route and in the same direction without being turned round, or where there are more curves on one hand than the other. This, then, ought to convince one that it takes time to distort truck frames on a new system—speaking generally, three years at the outside, if they are going to give at all. Once distorted, there is no difficulty in corrugating newly-laid checked rails, a matter which by this time has come under the notice of most tramway engineers. In a similar way the two smaller wheels will be found on the same side of trailing bogies on electric railways. Fig. 5 illustrates a typical example of two like pairs of defective wheels obtained from a strained trailing bogie. Now, if a train is composed of more or less strained trucks of this type, drawn by a locomotive, one might expect roaring rails, because the axles are free to lag and lock across the track gauge on any part of the road, according to the varying circumferences of the wheel tyres. Roaring rails have most irregular ridges and hollows not confined to any one length, and quite distinct in appearance from

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corrugations, though caused by one and the same thing; the climatic conditions and varying elasticity due to the different qualities of ballast and packing contribute their effect, with the result that the train is supported by wheels of varying circumferences, unchecked in their career, lagging and hopping along a track consisting of inequalities in rail level. Hammered roaring rails are the inevitable consequence. On the other hand, if the same train is driven by geared motors, the power of the motor overcomes the tendency of the wheels to lag, which therefore run steadily though skewed and unchecked. It is only when such skewed axles meet check rails that the leading tires tend to groove-lock. Then it is that the two combined effects (that is, the groove-locking and the wheel lag) are able to overcome the inertia of the motor, the opposing forces causing the axle to oscillate intermittently when checked. Hence corrugations can be produced at will, on checked curves or where check rails are used, be it on the straight or curved track. In the case of electric railways, any light depressions the trailing coach wheels might make on the rail are obliterated by the harshly acting and heavy motor coaches that follow. No corrugations or roaring rails are therefore to be found on the straight unchecked track of electrically operated railways.

Elasticity and Vibration.—A great deal has been said about rail vibration. The author fails to see why an ordinary tramway rail, laid in solid cement, should vibrate, unless it is caused to do so by the hammering action of skewed wheels, locking and oscillating in the groove, which in turn sets up a vibration of the car and rail. Where deep corrugations have been found the vibrations set up in the rail by the car passing over it cause the setts entirely to separate themselves from the rail, the rail eventually becoming waterlogged. Similar cases will be found where cars when negotiating points and crossings have a tendency to gallop, due to the inequalities in the points and road-bed setting up a periodicity of blows that synchronise with the car springs. Whether this periodicity can be made to agree with the corrugations on the tongue of the points and rail remains to be determined. With regard to bridge-constructed railways, one can feel and hear the vibrations of the structure when the approaching train is half a mile off, yet there is not the slightest sign of corrugations on the straight track when no check rails are used. Take the average case of a tramway where the track is laid like an anvil, and the speed thereon is 10 to 12 miles per hour: corrugations are formed of about 2 to 3 ins. pitch. Compare this with elevated and bridge-constructed electric railways running at 30 to 36 miles per hour, entirely laid with ordinary railway rails on longitudinal sleepers supported every 2 ft. 6 ins.: one would expect to find corrugations in proportion, say, of 6 to 9 ins. pitch; as a matter of fact, the corrugations on the checked curves referred to exceed these lengths considerably, due entirely to the elasticity of the track both horizontally and vertically; and here it may be noted that the corrugations are shorter in wave-lengths at the joints than in the middle of the rail, depending on the rigidity of the joints and fish-plates in question.

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This proves that the wave-length of corrugation varies with the speed of the vehicle and track elasticity. Speaking generally, the composition of the metal and methods of manufacturing 7-in. girder rails in the early steam tramway days and to-day are not much different, unless it be for the better, yet rails manufactured by every firm in the world have given trouble through corrugation since the advent of electric traction, and rails that did duty for steam traction on being utilised for electric traction corrugated after a few years' service, thus showing that the change in the rolling stock is responsible for the corrugations.

Cable Cars.—Very little is heard about corrugations with reference to cable traction, owing to the different method of applying the power to the axles. The speed not being high, the corrugations take considerably longer to form in the first instance, and are of smaller pitch compared with those found in connection with electric traction. There seems no reason for doubting that corrugations on cable roads are brought about by weak trucks on flat curves, as it is here that the greatest damage of all is done, forming the first factor in making corrugations. The unequal wheels oscillating in the grooves form regular corrugations of definite wave-length, though the wheels are not so harsh in their movements as with geared axles, wherein the two forces are acting against each other. As the width of the check rail varies, so will the pitch of the corrugations. It also follows that as the longitudinal play of the axle increases the corrugations will be formed at lower speeds. Hence the gradual extension of corrugations over the whole system, deeper at places according to the rail level and road camber.

Truck Design.—This matter of rail corrugation is now receiving the close attention of British manufacturers, the experience with early American designs and practice proving disastrous, as, in the hurry to secure cheap methods of production in order to compete with one another in foreign markets, the standard stamp of durability required in this country was not maintained. It follows, therefore, that a large percentage of the trucks under our street cars are not capable of meeting modern requirements, because of the inability of the frames to withstand side strains, so frequently found in city and suburban districts, where the flat curves (taken at a high speed) are usually frequent and of short radii. Such trucks may be cheap at the beginning, but constantly require repair, while at the same time they need more current to draw them, and are most expensive in the end, as many managers have learned to their sorrow. The present-day bogie truck frames of riveted and built-up construction, as used by most electric railway companies, carry the load in the centre, and are themselves supported upon equalising springs instead of on journal springs. This gives a short spring base for the frame, and in consequence, when the brakes are applied, the frame is pulled down at one end and pushed up at the other. The author has noticed frames tilting 3 ins. or 4 ins., bringing the life-guards down on the rail. This, of course, releases one pair of wheels of their share of the load, with

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liability at such times of derailment, especially with bogies fitted with one motor, where the total weights per axle vary. The tendency of this type of frame to tilt under brake action necessitates deeper flanges and wider treads than is practicable in electric services. The equalising bar bears directly upon the axle box, and when the horn slides are worn the boxes take up a rigid position at an acute angle to the jaws of the frame, causing a binding of the boxes and producing the vibration so noticeable in trucks of this design. Hence the lurch and jerk so easily detected when entering a curve, which eventually wrenches and jars the car body and passengers, quickly straining the trucks, with consequent loss of squareness and friction in the journals and motor bearings. It is therefore necessary to give up the riveted and built-up construction of bogie frames, which are not capable of

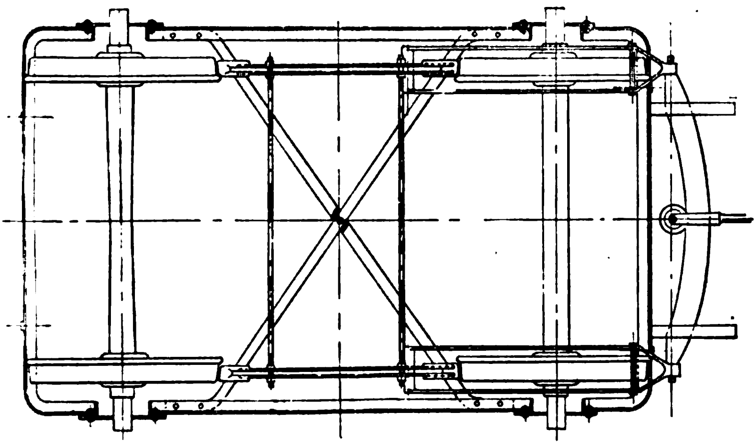

FIG. 8.—Method of Strengthening Truck (Angle Steel Under Frame).

withstanding the excessive strains of single-ended gear-driven axles on modern high-speed electric railways. It is entirely due to the weakness in bracing the two sides together, especially under the axle box, that the present day trucks are unable to withstand the severe side strain they are subject to. It will therefore be necessary to supplement the present trucks with suitable under frames well braced on either side of the wheels (see Fig. 8, with upper frame removed), in order to prevent the spreading and buckling of frames now going on, which in serious cases may amount to 1¼ ins. Adjustable thrust-plates have been tried by some of the prominent railways with little success, the tendency being to strain still further the already strained trucks. A motor truck for modern electric inter-urban services on railways and tramways has to withstand more severe shocks, strains, and vibrations (due to higher acceleration and retardation), and carries a much heavier load in comparison than the frames of locomotives or early tramways ever experienced.

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Attention must therefore be turned to stronger and more substantially designed trucks, with solid forged side frames, equally as strong under the axle box as over it, securely braced together, and capable of withstanding side strains and shocks in every direction, by the use of journal springs to bring the load to the wheels without interfering with the easy action of the boxes in the jaws, and, if possible, by equalising the weight on the frame before it is equalised on the wheels. In cases where there is only one motor per bogie it is advisable to have the brake gear towards the inside of the frame (see Fig. 9). By this means the leverage is proportioned to the weight on the axles, the total difference in weight carried by the motor and trailing axle varying from 30 cwts. to 2 tons. This arrangement still has the disadvantage of throwing excessive wear and strains on one side of the jaws or horn cheek-plates, eventually causing skewed and binding axle boxes, so noticeable on tramway systems that have been running for some considerable time with trucks not provided with renewable horn cheek-plates. In the author's opinion the time is not far distant

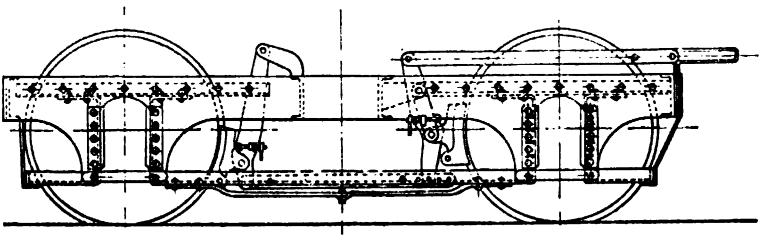

FIG. 9.

when brake blocks will be fitted on either side of the wheel, especially for street traction. The difficulty with horn slides would then be obviated, with a corresponding reduction in leverage and saving of labour on motor-men. Regarding the possibilities of wheel skidding, a suitable tachometer or indicator fixed at each end of the car would give a visual warning to the motor-man when the car wheels were skidding. Some careful observations have been made with reference to the effects of retardation on the rails. With heavy electric trains running at 40 to 60 miles per hour only barely visible wavy skin depressions appeared on the rails after a hard application of the brakes, the depressions being distorted and finally obliterated by the next train. Sudden braking operates unfavourably on the superstructure, in the sense that the rails are subjected to vibration, and consequently the substructure gets separated. This action has gone on for years at the same place without creating any impression upon the head of the rail. There is therefore no ground for assuming that the application of brakes has any connection with corrugations or roaring rails.

To sum up briefly, corrugations are caused, directly or indirectly, by lateral play in weak trucks, the weakness being intensified by

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unsymmetrically driven axles. The whole question can, however, be finally settled and tested only by a full technical investigation carried out by the Board of Trade or a Royal Commission.

In conclusion, the author would point out that, however erroneous these observations may seem, and however crude the suggested remedies may appear, they are the direct result of practical experience gained since the year in which accelerated electric railway traction made a substantial start. The paper is the outcome of several years' daily labour and thought, and is here submitted to criticism as an earnest attempt to solve the vexed question of rail corrugations.

Discussion.

Mr. H. M. Sayers: I think the author is on the right track as regards the cause of corrugation; the rolling stock is the culprit. There are more ways than one in which the rolling stock brings about the result described under the general head of "corrugation," and there are more kinds of corrugation than one. All the actions mentioned by the author of the rolling stock upon the rails reduce themselves to one character: they are all chattering actions. The action of a skewed axle is a chattering action. It chatters just as a badly fitted window chatters, or just as a badly fitted drawer jams and slips, and then jams and slips again. Flange binding, which may be caused by the skewing of axles or by the rails being out of gauge, also produces chattering. Wheels of the same diameters running on curves produce a torsional vibration of the axle. The axle twists between the two wheels, up to the point at which the torsion overcomes the adhesion of the wheel on the rail, and then it slips. So that I think we may say that vibrations of short period, or chattering, caused in a number of different ways, lead to corrugations. It is a common occurrence to see corrugations on one rail only—very frequently the outer rail of a curve. There I think it is clearly attributable to the torsional vibration of the axles, due to the fact that one wheel or the other must jump, because while travelling over slightly different lengths of route they must make the same number of revolutions. The rail which is corrugated is generally the off-side rail in double-track roads. That rail is nearer the centre of the road, and is the higher of the two owing to the camber of the roadway. It is better to lay a tramway track quite level across, but the requirements of the road authority usually interfere with that, and it is common to give ½ in. difference of level between the two rails. That puts a little more weight on to the higher rail, and therefore, when slipping occurs, the higher rail is the one to get punished. The author does not think that braking produces corrugations. I have had some reason to believe that it does. The only corrugations I have ever seen on cable tramways are at places where braking is applied to every car. On the Edinburgh cable lines on the north side, the termini in South Frederick Street and Hanover Street, are on steep down grades towards Princes Street. Every car coming

Mr. Sayers.

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Mr. Sayers.

into the terminus puts its brakes on as it gets down to the dead end, and in each case pronounced corrugations occur on the approaching road.* In some of the District Railway stations, since electrification has been in use, corrugation on the approaching side is well marked. It never gets very well developed, because, besides corrugation, there is severe abrasive action, and the corrugations have no time to get deep. The author referred to roaring rails and Indian experience with regard to them. In Mr. G. Moyle's paper † there are a number of reports by Indian railway officials. For instance, the Superintendent of the Way and Works on the Burma Railways remarks: "Roaring rails are generally found at approaches to stations where brakes are first applied. They are more frequent amongst the 44-lb. rails than amongst those of the heavier sections, which is probably due to the lighter rails having undergone more work. There are no roarers amongst the iron rails. This noisiness is caused by the wheels rolling over slight corrugations on the head of the rails. These corrugations may be due to the repetition of the following process: The application of the brake lifts the wheels from the rails; when this happens the brake ceases to act and the wheel falls down on the rails, the brake then begins to act again, and so on, the flexibility of the spring accentuating this undulatory motion." I have seen a number of examples of the same thing on tramways. I had the curiosity to make a survey of the London County Council tramways from Kennington Gate to Streatham about eighteen months ago; the line had been running electrically for about eighteen months. There were ten places on one track at which corrugations were very evident. In every place but one it was approaching a stop. The one exception was on the downward road of Brixton Hill, where the cars had the brakes on all the time. I take it that the corrugation in that case is set up by incipient skidding. The liability of tramway rails to this infliction, as compared with railway rails, is due to the fact that they are grooved rails, and that the flange is too near a fit to the groove. The author's observations confirm that. He finds that corrugations occur on checked curves on electric railways. A checked curve is nearly equivalent to a grooved rail.

It would seem possible to get over the difficulty by increasing the distance between the running rail and the check rail. On tramways we cannot make the groove what we like. The old tramway groove was 1 in. wide; by very great perseverance we have got the Board of Trade to increase that to $1\frac{1}{8}$ in. on the straight and to $1\frac{1}{4}$ in. for curves. We cannot compensate for curvature on tramways by widening the gauge, because widening the gauge eases the outside of the flange but brings the check nearer the inside of the flange. The proper way to lay a tramway round a curve is to consider the wheel base, the wheel diameter,

* This observation was made in May, 1905. On a visit to Edinburgh, since these remarks were made, I find that corrugations are not now to be seen on the lines mentioned.

† Technical paper No. 158, issued by the Indian Government; *Electrician*, vol. 57, p. 334.

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and flange dimensions of the rolling stock that is going to run on it, and to gauge that curve by a template on which the four-wheel flanges are represented. It comes to this, that the gauge line is not radial but parallel to a radius of the curve through the centre of the wheel base. That gives the best gauge, but there are limits. In the case of a tramway of 3 ft. 6 in. gauge, with a 6 ft. wheel base, with flanges ⅝ in. in thickness and 1 in. groove, one cannot run round a 50 ft. curve without flange-binding. Flange-binding will set up corrugations unless it is too severe, when the corrugations do not persist; everything is carved out, and sooner or later the groove is wide enough to prevent binding. The author suggests that it is common practice to run a flange ¾ in. wide in a 1 in. groove. I have tried to do it myself, because a few years ago I made a great many experiments on the best thickness of flange for durability and easy running, and I found that a ¾ in. flange with a 1 in. groove was not practicable; the flanges broke. If it is still done it may account for the fashion of steel tires. I found for a 1 in. groove ⅝ in. was the greatest thickness workable. On the standard rails, with 1⅛ in. groove, we can do with ¾ in. Then the author says that tramway rails run over by steam locomotives have in many cases corrugated when run over by electric cars. I should like to know where that has happened. In nearly every case in my experience steam-driven tramways when converted to electric traction have been completely relaid. There has been one exception to that in my experience, and there no corrugation took place. The rails were very early steel rails—very soft. They cut out pretty badly, but I do not think they had sufficient time to corrugate. So much for the causes of corrugation. What is the real effect? What is corrugation, anyhow? I suggest that the effect of chattering, which I have mentioned, is that the surface of the rail table is rolled up into little hillocks, the rolling up and the depressions corresponding to the alternate dragging and grinding by the wheels. The metal is really rolled up in that fashion, because the high parts are burred over into the groove; they eventually foul the flanges and are burnished by them. The easiest way of detecting corrugations on tramway rails is to get a good side light on the rail. Walk along parallel to the rail, and these burnished pieces reflect light like little pieces of silver. There are some fine examples to be seen on the Brighton Road, Croydon, on any sunny afternoon. For steel to roll under pressure in that fashion it must be ductile and tough. I suggest that corrugations would not occur with hard rails. Unfortunately, English steel rail rollers will not make them; they simply refuse. When they receive specifications, they say they will not do it or cannot do it. They have been supported, I think unfortunately, by the Engineering Standards Committee. The British Standard Specification for tramway rails allows the carbon content to vary from 0·4 to 0·55 per cent. The correct specification, as dictated by experience, will not allow of less carbon than 0·6 per cent. The manganese allowed is 0·7 to 1 per cent.; and the phosphorus and sulphur up to 0·08 per cent. Each of those constituents is too high. Manganese, I think, assists

Mr. Sayers.

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Mr. Sayers. cold rolling, but English makers say that a high carbon rail must also contain plenty of manganese, otherwise it will be brittle. I should not be afraid of the risk of a brittle rail if they would give us a hard rail. The proof that high carbon rails do not corrugate is found in the fact that many lines built six to nine years ago with hard German and Belgian rails show no corrugation. Those lines were built by the British Electric Traction Company between 1898 and 1903. The British Electric Traction Company was advised by a very competent tramway engineer to use hard rails. They could not get hard rails in this country; but they bought at least 10,000 tons from German and Belgian makers; and I do not know of a single case where these rails are laid where corrugations have occurred to any noticeable extent. I am told that on one line of about 30 miles in length there are 60 ft. of corrugations; I have not seen it. The rolling stock on these lines is of a most diverse character; there are four-wheel cars and bogie cars of many different manufactures and types; there are single-deck and double-deck cars; but the thing that differentiates these lines from nearly all the lines in which corrugation has given trouble is the rail—the hard rail with 0·6 carbon, rather high silicon, low manganese and low phosphorus and sulphur. I suggest that that is one of the things that ought to be adopted to prevent rail corrugation.

Prof. Carus-Wilson. Professor CARUS-WILSON: We have had a great many suggestions made about rail corrugation, that it is due to this or that; to-night Mr. Panton comes before us with a fresh suggestion, which I take to be in the main that corrugations are due to inferior rolling stock. Before considering his suggestion, I should like to outline in a few words what is actually known about corrugations at the present time. The first and most enlightening fact is that corrugation takes time to appear on a line. Of course there are exceptions, but generally it will be admitted that it takes time for corrugations to appear on any line. Some tramway managers congratulate themselves that they have been running for two or three years and have no corrugations, and then in the third or fourth year the corrugations show up. I think that is a very illuminating fact, for it indicates that there is some process taking place, either in the rolling stock or in the track, which is necessary before corrugations can develop; and the question is, What is that process? It must be a process of deterioration of some kind, either of the rails or of the rolling stock; it must be one or the other. The second fact that I think most people agree about is, that these corrugations make their first appearance on the outer rails of large radius curves. That seems to show that corrugations are due to an action similar to that which accompanies the passage of a wheel or car round a curve—that is, to a skew action; because the essential peculiarity of the passage of a truck round a curve is a skew relation of the axle to the normal to the curve. Fact number three is one that perhaps has been most debated, and that was raised by Mr. Sayers just now, namely, as regards the question of the rail itself. Many people have insisted that corrugations are due to the rail, that there is

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Prof. Carus-Wilson.

something wrong with the rail, either with the way it has been rolled, or with the hardness or softness, or something else about it. A conclusive test was made to settle that question. A rail was taken out of a part of the track which was corrugated and exchanged with another rail from another part of the track which was not corrugated. What happened? The smooth rail began corrugating and the corrugated rail began to get smooth. That goes a long way towards clearing the rail of the responsibility of corrugations. Alluding for a moment to the point raised by Mr. Sayers as to the hardness of the rail, that a hard rail will prevent corrugations, two test specimens were sent to be tested; one was a very badly corrugated rail and the other was a smooth rail. The smooth rail was easily cut up for testing purposes; the corrugated rail was so hard it could scarcely be touched by the saw. That militates against the theory that a hard rail is going to prevent corrugations. It seems to me that the rail has not deserved the severe criticism that it has received in this connection. Corrugations have been attributed to the action of the rolling, but this seems to me put out of court by the simple fact that the pitch of the corrugations on the rail does not correspond with the distance on the pitch circle of the pinions which work the rolls, the theory put forward being that the looseness of the pinions was accountable for the irregularity of the way in which the rails came out of the rolls. I therefore cannot see that the rolls are in any way accountable for the corrugations. The way in which the rail is laid is quite a different question. A peculiarity of corrugations is that in walking along a line, one rail is seen to be corrugated, and the rail fished to it, just immediately next to it, may be perfectly smooth, and this intermittent character of corrugations is a feature of the problem. I take it, from what I have already said about the character of the rail, that the intermittent character cannot be due to the fact that the successive rails are of different constitution, that it is not due to the metal of which the rail is made, but that it must in some way be due to the way in which the rails are laid. It may be said that the rails are all laid right along on the same plan. Directly one examines the way in which rails are laid one finds that is not strictly true; it is the exception, for example, to find rails laid accurately to gauge. The gauge is continually varying, and the level of the rails is always changing from point to point—a very small change, but quite enough, taken in conjunction with the question of the difference of gauge, to suggest the possibility that the existence of corrugation at any particular point may be due to irregularity in the track, which causes the car, or the wheels of the car, to make an attack as it were upon the rails at that point always in the same way. If the rail was absolutely smooth, level, and true to gauge, the car would make its way along the track and would never attack any bit of line more than any other; that is, it would be always oscillating and changing its position from point to point, and every car that came over the track would attack the rail in a different way. So that, as a fourth fact, I submit that the way in

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Prof. Carus-Wilson.

which the rails are laid has something to do with corrugations. I do not share the opinion of those who think the vibration of the track is the cause of corrugation. When a thing cannot be explained in any other way, it is very easy to say it is due to vibration. But before an argument of that kind is of any value, it has to be shown why the rails should vibrate and that they do vibrate. The fifth fact I would refer to is that the local conditions of the track have a great deal to do with it. Any one who has read Mr. Moyle's paper must be struck that the one outstanding fact demonstrated in that paper is that in most cases in India roaring rails occurred on a track which was boxed with burnt brick, and that when the brick-boxing was removed and replaced by earth the roaring disappeared. That shows that the character of the ground in the neighbourhood of the rail has a good deal to do with it. I do not lay down any absolute rule, but I have come to this conclusion from an examination of several tramway routes, that the existence of macadam sides, where a hard and gritty dust is produced, is favourable to the production of corrugations. There are, then, three things which experience has shown to be contributory to corrugations: firstly, some deterioration, probably in the rolling stock; secondly, irregularities in the laying of the rail; and, thirdly, the local conditions of the track. Now, what light does Mr. Panton's paper throw on these three questions? His argument is mainly that corrugation is due to defective rolling stock; he gives conclusive proof of the existence of distorted trucks, and shows how such distorted trucks can, when moving at speed, injure a rail. He does not, however, explain what is the connection between flange action and corrugations. He writes only in a general way, and says that the action of the flange on the rail may cause chattering. But we want something more than that. It is not sufficient to state that the action of a flange moving at an angle to the rail produces a chattering action, and that this is the cause of corrugation.

The most important part of the paper is where the angular shear or distorted shape of the truck is attributed to side gearing of the motors. I must say that I cannot follow him in his argument. He says that the spur wheel of a geared motor tends to get away from the gear wheel, and that it will do so in time, that is to say, when the bearings get worn, and he concludes from this that a side-geared motor tends to push the truck out of shape. I am afraid I must be very dense, but I cannot see how that can come about, because surely the results of the tendency of two geared wheels to get apart from one another is balanced by the motor frame which holds them both. How can any action between the two gear wheels of a geared motor produce any resultant distorting action on the bogie frame which holds the motor? At the bottom of page 5 he quotes the case of the equipment on the Liverpool Overhead Railway as a proof that a side-geared motor distorts the bogie. He says there that for ten years the cars on that railway ran with ungeared motors on the axles, and that there was no sign whatever of corrugation; but that directly the side-geared motor was introduced,

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corrugation and other troubles began to crop up; hence, he says, corrugation is due to side-geared motors. But has he stated all the facts of the case? He knows much more about the Liverpool Overhead Railway than I do, and I stand to be corrected if my figures are not right; but, as I understand it, in the original equipment of the line the motors were of about 40 H.P., and ran the trains at an average speed of about 16 miles an hour. When side gearing was introduced, instead of having 40-H.P. motors, 100-H.P. motors were put in, and the speed was raised from 16 to 22 miles an hour, an increase of speed of 40 per cent. On rounding a curve that would mean an increase of 100 per cent. in the flange action. Surely the true explanation of the troubles that occurred when the new equipment was installed was simply the heavier motors running round the curves at 40 per cent. greater speed and with something like 100 per cent. increase in flange action. In my opinion the cause of the check cutting has nothing to do with the side-geared motors, but to the high speed at which the curves are taken; in fact, I think it very likely that without the check rails the trains would leave the line at the sharper curves. Mr. Panton has given us additional evidence of the distorting strains brought to bear on trucks on electric railways with sharp curves, and states that these produce a permanent deformation of the trucks, resulting in the axles being out of square with the rail, with consequent increased flange action; but it seems to me we want a great deal more proof before we can say that this is certainly the cause of corrugation; we want to know precisely how this skew action of the axle produces the chattering action which is such a feature of the phenomenon; and until we have that further proof I do not think we can consider the problem as by any means solved. I am now conducting some tests on this question, the results of which I hope to have the opportunity of communicating at a later date. Prof. Carus-Wilson.

Mr. W. WORBY BEAUMONT: I came this evening to listen to the discussion on the paper rather than to make any remarks upon it, chiefly because I cannot find myself in agreement with any part of the paper as an explanation of the cause of corrugation. I will not enter now upon what I consider would be an explanation, for it would take a much longer time than the members would care to listen to any speaker. I will say that I think it has in part been touched upon already by Mr. Sayers. I might refer the members of this Institution to a paper which I read before the Institution of Civil Engineers in 1876, which was an explanation of the then unexplained causes of the fracture of railway tires, especially the causes which led to the fracture of those tires between, and not at the holes for the bolts that hold the tires on the wheels by the methods then adopted; and also to a paper that I read a few years ago, before the British Association, describing the application of the same reasoning to the fracture of railway rails, an explanation which was subsequently brought out fully in the report of the Royal Commission some time afterwards on the fracture of railway rails after certain severe accidents had happened. The main Mr. Beaumont.

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Mr. Beaumont.

reason for the origin of those stresses which set up the causes of fracture of tires and rails is the rolling action of the wheels on the rails, that rolling action being more and more severe with the smaller wheels and the heavier loads. In various ways engineers are constantly making use of the fact that steel, even of considerable hardness, can be rolled cold, and its form can be changed by simply the exercise of the pressure of a rolling thing upon the metal. It is somewhat strange that, though they expect and do get certain results in various sorts of manufactures, they somehow expect that those same results will not occur when they run a small tramway wheel under a heavy load on tramway rails. It has been suggested here that this action does not take place on railways, or that it takes place only in certain few cases, and that there are various special reasons for its taking place where it has done so. As a matter of fact an examination of the records of the growth of corrugation will show that it has taken place wherever there is any considerable weight running on rails. It takes place irregularly, as one would expect, just as it takes place irregularly under what seems to me the same conditions on the tramways in London, or any other of the tramways in this country. It is, for instance, felt more severely and noticed more rapidly on the outer curves of rather large curves on the tramways, to speak of London only; but it is also found that it sometimes arises even as quickly on the inner curves, for reasons which are quite open to us. It is found to take place on many tramlines more rapidly on the larger outer curves than anywhere else, also for reasons which are obvious when the extra weight is considered that comes on the table of the outer curve as a tramcar runs along at even moderate speeds. I feel quite satisfied that the rolling compression which takes place necessarily takes place in such a way that the material is pushed forward gradually—it would be extruded if it were a softer material—until it is run over by the running wheel, compressed and hammered until it, in fact, is so hard at these places that one can hardly touch it with any instrument; and that that must take place with almost precise regularity as to distance apart, with any one given rail of given composition, and that the difference in the distance, or I might call it the pitch of the corrugation, will depend almost entirely, so far as the rail itself is concerned, on its composition—not that either a rail which is more rapidly corrugated or one that is less so is necessarily bad as to composition.

Mr. Hawtayne.

Mr. W. C. C. Hawtayne: Like the last speaker, I came to the meeting intending only to listen, but something which Mr. Sayers said makes me rise for the purpose of confirming his statement as to the hardness of rails having a great deal to do with the subject. Until the British Standard Specification came out my firm were in the habit of using nothing but a very hard rail such as Mr. Sayers described. Practically the whole of our first rails came from three different firms in Belgium, and in not one single case have we had any corrugations showing up in those rails. It has not been until the last year or so when we adopted the English Standard Specification that we have had

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any cases of corrugation. I do not say that the softer rail is the sole cause of the trouble, but it is, I think, a contributory cause, as in no case has corrugation taken place upon the harder rails, although some of them have been down for six or seven years. Mr. Hawtayne.

Mr. W. M. MORDEY: Whatever the cause of the corrugation trouble it is clear that soft rails make it worse. May I therefore say a few words to relieve the minds of any engineers who think they cannot get hard rails in this country? It is true that the British Engineering Standards Committee has adopted what is called the British Engineering Standards composition for rails, but that is not adhered to in all cases. In one case in which I and Mr. Dawbarn had to be responsible for a large quantity of rails we specified a high carbon hard rail. The British Standards Committee, which had been sitting for some months, had produced the British Standard, and all the manufacturers came with our specification and said, "We cannot make this, but we will make the British Standard"; in fact, one of the most important of them said, "It is a physical impossibility to make this rail." We said, "We are very sorry to hear it, but as we happen to have obtained rails of this composition from abroad, we know it is not a physical impossibility to make them." The manufacturer said, "Then I had better go back and tell my works so"; and I replied, "Yes, I think you had."* The specification was accepted by foreign rail makers, not by British makers, who all quoted to the British standard; and we recommended the acceptance of a foreign tender. By mistake our clients did not formally accept the tender within the specified time, and the foreign mill, having filled itself up, subsequently declined the order. We then had to get new tenders, and were again urged to bow down to the British Standard. But we did not see why we should do that, and simply reissued the specification as it was. On the second occasion nearly all the British makers quoted to that specification, and the one who had said it was a physical impossibility to make it got the order, and carried it out satisfactorily. Mr. Mordey.

Mr. J. S. WARNER: I should be much obliged if the author would not mind stating the name of the truck he has in mind in the statement he has made near the bottom of page 8 with regard to design. It conveys the impression that he really considers that the truck makers intended that ¾ in. flange to move in a 1 in. groove. The idea of making a suspended truck to move laterally in that way is quite a different thing altogether. The wheel flange always must follow the track; it is the car body which moves relatively to the track, or rather, the track is always sinuous and the mass of the car body will ride over that track in a mathematically straight line as far as possible. This suspension which Maguire uses, and was used in Italy many years ago, allows the wheels to move transversely while the car body will pass on the straight line. It has nothing to do with the flange and the groove at all. Even Mr. Warner.

* Another important manufacturer told us that if we got the rails they would be very brittle. In the result the breakages amounted to about one rail per six miles of track.

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Mr. Warner. on a curve this purely transverse swing does not affect in the slightest the flange-groove clearance, because, while it cushions side-shocks a little, it does not steer the wheels and so alter the angle they make with the rail, straight or curved, at any instant.

Communicated.—A very considerable investigation into this and the allied problems extending over several years on the principal tramway systems in Europe, leads me to make the observation that if the existing, or some of the existing trucks, contain factors in their design or construction which cause rail corrugation, it is strange that they do so in one or two spots only over a large system.

With reference to truck design, we are so accustomed to the crude rigid wheel-base truck, whether bogie or single type, that the mechanical crudeness and enormous amount of surface skidding on so-called straight and curved track is lost sight of. The only alternative is the Pivotal truck, known in England as the Radial truck, and this has in every case given indifferent results, because the designers have overlooked the extremely important question of alignment and yield to track sinuosity on the straight. The great desideratum is to obtain in a four-wheeled car the admirable riding qualities of the swing-bolster bogies so very essential to modern high-speed railroad steadiness and comfort. This result I have obtained by methods which have been published elsewhere. I have frequently observed with my own truck, which has a transverse swing coupled with steering movement, a sudden transverse displacement where a kink in the track occurs of as much as 2 ins. In such a case a car body passes across the sudden change of track direction while the wheels are steered round, and the importance of this from a passenger or maintenance point of view is obvious. There is a paucity of adequate terms for dealing with the problem, but since a tramcar should not be deflected to every slight deviation of track, but should rather make a "bee-line" over the track, I have adopted the term "conformity" line to indicate the mathematical straight line of most efficient transition from one spot to another as modified by conformation to general track direction.

Dr. Hay. Dr. ALFRED HAY (*communicated*): As I have been taking an interest for some time past in the author's investigations on rail corrugation, I wish to express my appreciation of the excellent work done by him, and my admiration of the careful observations by which he has been led to frame his present theory of the way in which corrugations are caused. In view of the cumulative evidence amassed by Mr. Panton, it seems difficult to resist his conclusions. It is to be hoped that a closer understanding of the source of this serious trouble will lead to methods of construction which will result in a more or less complete elimination of it.

Mr. Neachell. Mr. E. J. NEACHELL (*communicated*): It is mentioned (on page 5) that no corrugations appeared on the Liverpool Overhead Railway when the armatures of the motors were built direct on the axles, but that corrugations showed soon after using geared motors. This would make it appear that the whole of the corrugation trouble is due to the

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gearing of the motors, but at the same time it must be taken into consideration that other factors in the working of the line underwent changes when geared motors were introduced, and the principal of these, I would suggest, is the increase of speed from a maximum of 25 miles per hour to a maximum of 40 miles per hour, and from an average speed of 12½ miles to one of 19 miles per hour. Mr. Neachell.

Under the heading of "Defective Tramway Rolling Stock" (page 6) the author points out the tendency of the gearwheel to get away from the pinion, owing to wear of the various parts, with the result that the truck or bogie is forced out of square. This raises the question as to whether tram rails on which radial trucks are used show signs of corrugations. I have not heard that such roads are free from this almost universal trouble, and if this be so, would it not be advisable to adopt a design of axle-box and motor bearing in which any such movements as the author speaks of could be eliminated, and at the same time to strengthen the trucks so that they could not change from their original shape?

With regard to the remarks as to the refitting of a certain corporation's trucks (see page 8), I gather that these trucks were overhauled and put together so as to make them absolutely square, and that all worn parts were renewed and carefully adjusted, so that they would tend to wipe out the already existing corrugations in the rails, until such time as wear again takes place, when corrugating will recommence.

Mr. PANTON (*in reply*): Mr. Sayers does not seem to be aware that in the various places where electric traction has been substituted for steam the tram rails corrugated after a few years' service. The following, amongst others, have had this experience: Aberdeen, Darwen, Wigan, Huddersfield, Blackburn, etc. I fail to see how braking and incipient skidding of wheels can cause corrugations of definite wave length, as the skin depressions caused by retardation vary with every car, according to the speed and pressure applied to the brake-shoe. The act of braking creates a dragging action which causes a fine wave on the head of the rail, perceptible to the eye only, and similar to those which may be seen on a newly cleaned locomotive, or those noticed by Mr. Sayers on the L.C.C. tramways after eighteen months' running. Should he care to revisit the same place he will still find the same result no further developed. Mr. Panton.

Now corrugations properly so called exist abundantly where brakes are never used. In speaking of corrugations I mean the roughness of the rail that can be felt by sliding the foot along the rail, and which is easily detected. To say that the wheels alternately slip and roll is not in my opinion a satisfactory explanation, and it fails to account for the corrugation of the check rail. As regards increasing the distance between the check and running rails as suggested, using the check rail more in the way of a safeguard against derailment, the accompanying Fig. A gives the result of a 90-lb. outer rail on a super-elevated curve after eighteen months' use, the service of trains being one of ten minutes

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Mr. Panton. headway with sleeper and ballast permanent way. For further particulars regarding the use of checks and harder rails to prevent corrugations, I will refer Mr. Sayers to a recent article published in the *Street Railway Journal*, December 29, 1906, giving experience of the Boston Elevated Railway, on which manganese steel and a great variety of carbon rails of varying percentages and compositions have been tested, with a view to securing longer life of the rails, but all to no purpose, 30 to 40 per cent. of the rail renewals being caused by corrugations on curves, no corrugations being found on the straight portion of the track.

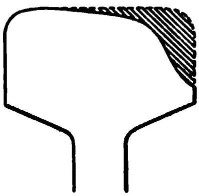

FIG. A.

Mr. Mordey, in trying to relieve the minds of tramway engineers as to the purchase of harder rails, has also reminded us that the breakages amount to about one rail per 6 miles of track, a harder rail is therefore a brittle rail. In this connection, I fail to see why it should be necessary to have harder rails for electric tramways and railways, when our present steam railroads, with heavier rolling stock and greater speed, require nothing further than the British Standard Specification.

Professor Carus-Wilson differs from the first speaker as regards the rail theory, upholding the view expressed in the paper. The comparatively long time taken to first form corrugations, and the short time in which they appear after relaying with new rails, combined with the results obtained by changing rails from one place to another, and the corrugation of the inside of the check rail seems to point clearly to inferior rolling stock as being the true cause of the trouble. Professor Carus-Wilson's figures regarding the Liverpool Overhead Railway are not quite accurate. I am, of course, fully aware of the effects of the higher acceleration and retardation, and the extra wear and tear caused thereby. The effects of check cutting and flange wear might have been considerably reduced by increasing the distance between the check and rail to suit the increased speed had the axles been symmetrically driven. Even under existing conditions check cutting can be obviated by applying a thin layer of fat to the check on short chain curves, provided the wheel diameters are kept equal and well trimmed. Thus it would appear that check cutting and acceleration have no relation to corrugations, except in so far as the increased speed would produce corrugations of a correspondingly longer wave-length.

With reference to flange action and its relation to corrugations, I would again refer Professor Carus-Wilson to the paper, pages 10 and 11, where an explanation is given of how unequal tires are formed, and their effect on the road level and track gauge. In grinding hollows in the rail, the motor tire at the geared end or leading side also grinds away as shown in Fig. 4. This grinding action produces unequal tires on the same axle which oscillates and further increases the trouble. This oscillation of the axle is accountable for the corruga-

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Mr. Panton.

tions that are found on the inner side of the check rail; as it oscillates and revolves it scoops out intermittent hollows in the rail, the length of the hollows being governed by the speed of the vehicle and track elasticity. If Professor Carus-Wilson takes the trouble to examine the pinion and gear in a motor case, he will find the teeth worn to a wedge shape, indicating that the armature shaft and motor axle are not running parallel to each other. This thrust or skew relation of the axle to the truck can be measured when the car is over the pit; it of course increases when the power is applied to the motor. In transmitting the power to a weak frame the tendency is thus to skew still further the already skewed axle (as far as the horizontal movement of the motor case suspensions will allow), resulting in wearing unequally the truck frame jaws, where in most cases no renewable horn plates are used, so that the longer they run the worse they get, the axle boxes eventually binding in the jaws. Professor Carus-Wilson has only to try the squareness of a few bogies and trucks, when he will find that the cross corners vary from $\frac{5}{8}$ in. to $\frac{3}{4}$ in., in order to satisfy himself of the soundness of the explanation given as to how diamond-shaped truck frames are formed. We see then the advisability of fixing the horizontal movement of the motor case on the motor axle and suspension. We should then get the motor case to act in unison with the car body and truck, or bogie frame, at the same time assisting the axle to take a super-elevated curve, instead of retarding the axle as is the case at present when the dead weight of the motor acts in a disastrous manner on weak frames, the lateral play increasing daily owing to the dead weight on the axle bumping the pedestals asunder, especially under the axle box, where no provision is made to retain the original shape. Professor Carus-Wilson does not state all the facts brought to light in the Indian investigation. Thus roaring rails did *not* disappear in all cases with the removal of the brick boxing. Again, on the same steam railways "roaring rails" occurred on wooden sleepers and on bridges where no burnt brick was used, much in the same way as "corrugations" occur on electrically operated elevated railroads composed of bridge construction. It must also be borne in mind that all sorts and conditions of packing have been tried in this country on some of the largest tramway undertakings without any beneficial effect.

Mr. Beaumont appears neither to agree with the views put forward in the paper nor to give any definite reason for thinking otherwise. Surely he does not mean that our present tramways carry heavy loads on small wheels. Our steam railways carry much heavier loads in comparison without being troubled with corrugations; the few defects that do occur being confined to roaring rails of irregular pitch as prevalent on foreign railways. Allowing, as railway locomotive engineers do, 1 in. of diameter for each mile per hour speed, tramway wheels should, in accordance with this rule, be 12 ins. to 15 ins. in diameter. Since at the present time they are double that size there seems to be no reasonable ground for complaint. Having larger wheels would also increase the height of the centre of gravity, thereby

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Mr. Panton. increasing the vertical pressure on the outer rail of a curve when the car or train was under the influence of centrifugal force. Again, the Liverpool Overhead Railway Company, with large wheels and very light rolling stock to suit the circumstances, have no corrugations on the straight track, with the same delivery of rails that have corrugated on curves. How are the above results to be accounted for on the rolling compression theory put forward by Mr. Beaumont, according to which the metal is compressed and eventually run over by the running wheels? and how is it that the inside of the check rail is corrugated to an equal extent, the corrugations being parallel to that on the crown of the rail? Further, it is hard to understand how the pitch of the corrugations can depend on the composition of the rail. Up to the present the pitch has been found to increase with the speed and track elasticity.

In reply to Mr. Warner, the truck referred to is by Peckham; the truck maker would not intend a ¾ in. flange to run in a 1 in. groove; it would be the specification, which varies in many cases. Engineers vary in their opinion regarding the size of the flange and the groove.

Mr. Warner has referred to radial trucks. These, I am given to understand, produce unknown flange shapes in about six months' time. Radial trucks have not been found necessary in the case of steam railways, and I do not see why they should be required for electric tramways. Mr. Warner points out how the Maguire suspension allows the wheels to move transversely, but how can they do so without the necessary flange groove clearance? Mr. Warner makes the mistake of supposing that the corrugations are confined to a few spots only over a large system. This impression I have no doubt is formed from the present condition of the London County Council track. If he will only wait the allotted span, corrugations will be found there wherever a sufficient speed is attained. The lateral movement of the car body unaccompanied by any lateral movement of the wheel tread, would further tend to throw undue pressure on one side or the other of the truck according to the speed, especially on curves or straight tracks where the road camber represents ½ in. of the difference between the rails. This undue and constantly recurring pressure on one side of the car would cause unequal wear of tyres, and corrugations.

Considering the slow speed of electric cars I believe the "L" rail with conveniently arranged road camber at curves would greatly help matters.

I feel confident that if designers of electric railways and tramways would pay due attention to the design of high speed and heavy locomotives, there would be no difficulty on account of rails corrugating.

The PRESIDENT: I will ask you to pass a hearty vote of thanks to Mr. Panton for his interesting paper.

The resolution of thanks was put and carried by acclamation.

The meeting adjourned at 9.30 p.m.

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Proceedings of the Four Hundred and Fifty-sixth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, W.C., on Thursday evening, April 18, 1907—Dr. R. T. Glazebrook, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on March 21, 1907, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members :—

Harry Green.
Rupert M. Moberly.
James Stormont.
L. C. B. Trimnell.

From the class of Students to that of Associate Members :—

W. G. T. Pope.
Vincent D. Sorby.
Joseph J. Wolff.

Messrs. W. W. Cook and C. C. Paterson were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Philip A. Lange.
Richard Scott-Atkinson.

As Associate Members.

William James Blackhall.
Robert John Buchanan.
Laurence G. J. Epps.
James Muirhead.
Walter Fitzallen Simpson.

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As Students.

Arthur A. Anderson.
Roland Barker.
Edgar James Barnes.
Percy Edmond Cheesman.
Juan de la Cruz Tapia Contreras.
Jaquim Romeo Correa de Noronha.
E. A. G. Harvie.
Gerald Hayes.
Edward John Middleton.
David George Pennington.
Arthur Douglas Richardson.
Cyril Augustus Richardson.
Kenneth Vere Starkey.
George Kingston Sherlock Thomas.
Edward Gerald Grove Thompson.
R. Alan S. Thwaites.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. F. W. Clements, A. A. Crawford, Prof. J. Epstein, W. McGeoch; and to the *Benevolent Fund* from The Electrical Engineers Ball Committee, M. M. Gillespie, J. Gilligan, M. Heaphy, A. W. Mindo, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have been asked by the Council to announce the publication of a revised edition of the Wiring Rules (see page 231). When the work of revision was begun, representations were made that the new rules should be made as comprehensive as possible, so as to be acceptable to all branches of the profession. Accordingly, a Committee was constituted to include representatives of the Incorporated Municipal Electrical Association, the Electrical Contractors' Association, the Electrical Engineers of two of the leading Fire Insurance Offices, besides members of the Institution. Further, the Committee has had the co-operation of the Engineering Standards' Committee and of the Cable Makers' Association, and it has been ably assisted by Professor A. Schwartz, who carried out tests on flexibles for them. The Committee has been appointed as a Standing Committee, and will be pleased to consider any amendments to the Rules which may be suggested from time to time, if they are sent to the Secretary in the shape of definitely worded new paragraphs, or amendments of existing paragraphs.

I think those of you who have been able to see the Rules as they now stand will realise that our Committee have had a very arduous piece of work to carry through in producing them in their present comprehensive form, and that a very real debt of gratitude is due, not only from the profession, but from all users of electricity, for the work that has been carried out by them. It is fortunate, I think, that this notice should be given to-night, for the reason that the work of the Committee has been to no small degree facilitated by the researches and investigations of Professor Schwartz, who is to read us a paper this evening, and some of the results of his paper have been the basis of some of the important recommendations of our Committee. I have great pleasure in asking Professor Schwartz to give us his paper.

The following paper was read and discussed:—

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"FLEXIBLES," WITH NOTES ON THE TESTING OF RUBBER.

By PROFESSOR ALFRED SCHWARTZ, Member.

(*Paper read April* 18, 1907.)

SUMMARY OF CONTENTS.

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BIBLIOGRAPHY.

APPENDICES.—*Regulations for flexibles.*—A. American; B. French; C. German. *Detail examination of flexibles.*—D. Vulcanised rubber now on the market—E. Old flexibles insulated with pure and vulcanised rubber.

I. INTRODUCTORY.

The employment of twin flexible conductors for pendant lamps has been evolved from the early usage of bringing down the circuit leads and connecting to the platinum loops sealed into the lamp bulbs. The flexible thus filled the double *rôle* of supplying energy to the lamps and at the same time served as their support. The wires were twisted together to render them more sightly, and the conductors were stranded to ensure the necessary flexibility for the lamps to hang vertically without adjustment and to overcome the inherent mechanical weakness of a solid copper wire of small diameter when subjected to repeated bending.

For the junction between the flexible and the circuit conductors, ceiling roses in the case of pendants, and plugs in the case of portable appliances have been evolved, while the junction between the flexible and the consuming device is now effected in the case of lamps by the lamp-holder, and in other cases by means of plugs, connectors, and sweating thimbles.

At the present time flexibles are extensively employed for the following purposes:—

- Pendants and clusters.
- Counterweight fittings.
- Portable lamps.
- Wiring of fittings (electrolier and fixture wire).
- Connections to radiators and portable heating and cooking apparatus.
- Connections to brushes of dynamos and motors.
- Special systems of interior wiring.

These manifold uses and the varied conditions of environment in actual practice have been responsible for the number of grades in which flexible has been put upon the market. The type of insulation employed may be either a simple cotton covering with a protective braiding as used for dynamo flexible, one or more layers of pure rubber tape put on spirally under tension, or of vulcanised rubber or a combination of pure and vulcanised rubbers, together with a protective braiding.

There is a general consensus of opinion amongst engineers that the flexible is the weakest part of an electrical installation. If this is so, we are ourselves largely to blame for our neglect of the matter. It is curious to reflect that after the elaborate care that has been exercised to keep well-insulated conductors apart (when not enclosed in non-flammable tubes) in all other portions of the installation, we should have come to regard with complacency the violent forcing together of two

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comparatively poorly insulated conductors in positions where they are exposed to considerable heat and are liable to mechanical strains, as in the lamp-holder with single-hole cord-grip so commonly employed at the present time.

Unfortunately, there are no records published by the English fire offices in which fires caused by electricity are classified in detail. An examination of the reports of the Fire Salvage Association of Liverpool for the years 1894–1905 inclusive shows that during that period out of 9,711 fires in that city 666 were attributed to gas and only 74 to electricity, but as no details are given, it is impossible to say to what extent flexibles were concerned. Mr. W. W. Lackie* states that out of 35 fires during the years 1902–1904 attributed to electrical causes in the Glasgow system 5 were due to defective twin flexibles. The author has examined the admirable reports on fires due to electricity issued by the Electrical Bureau of the National Board of Fire Underwriters, New York, and has summarised the causes of such fires reported during the last year. Although the conditions obtaining in England and America are not precisely similar, yet the results given in Table I., below, may not be without interest as indicating the extent to which flexibles are concerned in such fires. These results do not include the total number of fires reported as attributable to electricity, but are taken from the summarised headings under which the causes of the fires have been classified. As a typical example of a detailed report of a fire of which flexible was the cause the following may be cited :—

"(3321) *Long pendant cord* had been knotted to take up surplus and to provide proper adjustment of lamp used for reading purposes over a bed. The constant abrasion and kinking of the insulation caused by this arrangement was finally sufficient to result in short circuit of flexible cord, which threw molten metal and burning insulation on the bed beneath."

TABLE I.

Summary of Reports of Electrical Fires. Electrical Bureau of the National Board of Fire Underwriters, New York, July, 1905, to July, 1906.

Cause.	No. of Fires.
Earths on motor and lighting circuits	71
Dynamos and motors	21
Rheostats	15
Blown fuses	12
Incandescent lamps	15
Crosses between high and low potential circuits ...	23
Lightning entering over service wires	13
†Overfused circuits...	3
†Lamp flexible hanging on nail	4
†Defective joints and contacts	13
†Short circuits on interior wiring...	79

* *Journal Institution of Electrical Engineers*, vol. 35, 1905, p. 118

† Denotes items with which flexibles are concerned.

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Faults in Flexible Installations.—On the Continent flexibles are employed more largely than in this country, in that their use is not restricted to lamps and portable appliances; but the wiring of the building itself is often carried out with flexibles supported on insulators. A description of the principal features of these flexible wiring systems is given later in this paper (see page 80), and the matter is only referred to here on account of the experience obtained on the Continent of flexibles in this wider field. In Appendices A, B, and C will be found *in extenso* the regulations, restrictions, specifications, and methods of testing in vogue in France, Germany, and the United States in connection with flexibles. These are given in detail, not only because it is usually instructive to compare the methods employed by different countries in dealing with a more or less common problem, but because a good deal of foreign flexible finds its way to the English market, and, further, because many of the art fittings imported from the Continent are provided with flexibles, which—although they might be satisfactory when used under the strictly specified conditions in the country of their origin—are here subjected to voltages and conditions for which they were never intended, with disastrous results.

With regard to the use of flexibles for wiring installations, which has an added interest to us at the present time in view of the desirability of cheapening the cost of wiring to small consumers, it has been found in Germany that unless the regulations laid down concerning this material (see Appendix C) are closely adhered to, and the best material employed, trouble is likely to ensue.

In the early days, when 110 volts only had to be dealt with, flexibles insulated with lapped rubber tape were successfully employed. When, however, 220 volts came into use this class of insulation was found to be insufficient, the faults mostly occurring in the switch wires. This was largely due to considerations of price which led to the employment of insulation material containing sometimes from 50 per cent. to 70 per cent. of rubber substitutes, and also to faulty manufacture in giving too small an overlap to the rubber tape spirals, so that in some cases the wire was uncovered. Under the new German regulations taped rubber flexibles may only be used in dry living rooms for pressures up to 125 volts. They may not be used under fabrics or for portable fittings, and may not be installed in cellars, under floors, in bedrooms, or halls. Vulcanised rubber in the form of a continuous sheath may, however, be used up to 1,000 volts for fixed apparatus and up to 500 volts for portable purposes. The trouble at 220 volts with taped rubber flexibles is due, not so much to a direct short circuit, which would blow the fuses, as to persistent arcs of low current value, which are carried by the fuses.

As already stated, these faults have been found to occur most frequently in the switch wires, and a reference to Fig. 1 will show the reason for this. It is evident that a short occurring at A or B would, by short-circuiting the lamp or other consuming device, allow of a considerable current rush, and blow the fuses; whereas if a short

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occurred in the switch wire at C only the switch is short-circuited, and the current in the arc is limited to that of the lamp or consuming device in the circuit. The arc thus formed travels slowly up the wires until the lamp leads are involved, when the fuses will blow. To

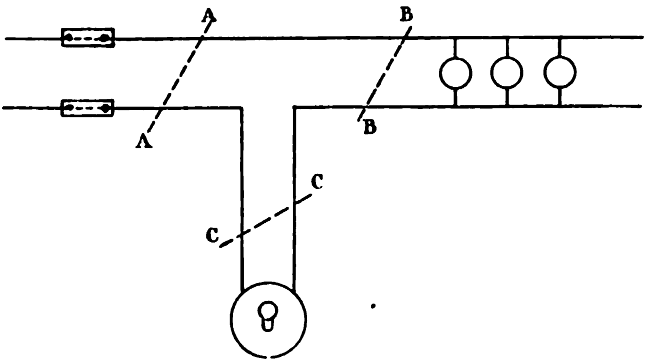

FIG. 1.

obviate this trouble with the switch wires Coninx* proposes to have laid up with the flexible for the switch connection a third wire, which should, if the switch is in the positive wire, be connected to the negative main at one end, and be carried down to the switch and there

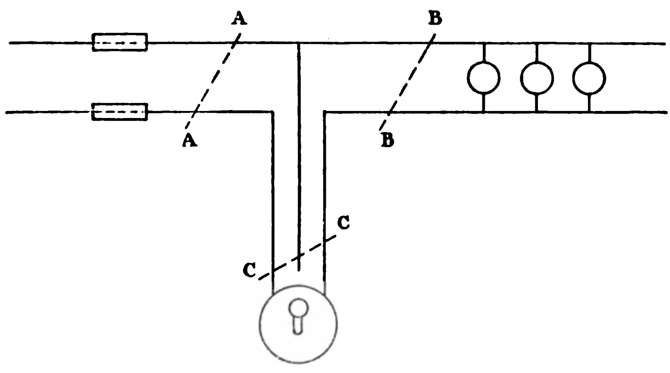

FIG. 2.

sealed off without being connected to it. A short-circuit in the switch wires would involve this third wire, and thus ensure the fuses blowing. The arrangement is shown diagrammatically in Fig. 2.

* *Handbuch der Electrotechnik*, vol. 6, part 2, p. 394.

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It is not unusual in Lancashire cotton mills, where the air is highly charged with moisture, and the flexibles are regularly brushed down in order to rid them of the adherent fluff with the brush used for cleaning down the machines, which is in consequence oily, to find that persistent arcs of low current value, and too small to blow the circuit fuses, are formed in the flexibles for pendant lamps. The arc travels up the flexible in the manner already referred to, but the limitation of the current in this case is due to the formation of a high-resistance arc across the carbonised insulation. It is interesting to note in this connection that in the United States and Germany the regulations call for an outer covering for the flexible, which shall be non-flammable. In spite of the fact that this regulation has been in force for many years the author is unaware that it is being actually complied with in a satisfactory manner. In mill and factory lighting, moreover, it is impossible for economic reasons to employ only 5-ampere circuits where long aisles are to be lit, consequently the blowing of a fuse brought about by the failure of a flexible may extinguish a large number of lights and result in the sudden throwing off of a large load and considerable confusion with the work. A return to the practice of fusing ceiling roses would therefore seem to be desirable in such cases, as the small fuse in the holder would in the first place be more likely to blow on the formation of the arc, and, secondly, would finally isolate the faulty flexible without interfering with the remainder of the circuit. Fuses in ceiling roses were abandoned chiefly because their inaccessible position rendered them likely to be largely over-fused for the sake of avoiding the trouble of replacement. This objection was valid when the branch circuits carried a large number of lamps, as, in the case of a ceiling rose fuse not blowing for a fault in the flexible, a considerable current might be fed through it to the fault. By limiting the branch circuit fuses to a carrying capacity of 5 amperes this danger is minimised, and the ceiling rose fuse, if fairly rated then, only becomes a source of annoyance, and we are well rid of it. But in the case of the lighting of long aisles the general safety of the circuit would undoubtedly be improved, and the amount of annoyance occasioned by the blowing of a fuse would certainly be curtailed by the re-introduction of the fused ceiling rose.

II. Conductors.

The conductors for flexibles are usually all twisted in one direction; they are sometimes, however, not twisted at all. This latter form is not desirable for any conductor that has to work backwards and forwards over a pulley, as the stress is not distributed evenly over the wires, which in consequence are liable to break.

It is very desirable that the number and gauge of wires for flexibles should be standardised, as cable makers are called upon at the present time to make up all sorts of odd sections.

The following particulars of conductors have recently been agreed

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by the Cable Makers' Association as being standard for flexibles. Table II. shows the number of wires of a given gauge with the equivalent solid wire. Table III. shows the number of wires of given gauge with the equivalent total sectional area in square inches. The vulcanised rubber C.M.A. flexible, which is the only standard material now on the market, consists of tinned copper wire 0·0076 in. diameter (No. 36 S.W.G.), made up as follows :—

Size.	Equivalent in Solid Wire.	Thickness of Insulation in Mils.
23/36	20	34
40/36	18	35
70/36	16	36
90/36	15	37
110/36	14	38

Table II.

Cable Makers' Association Standard Flexibles.

Number of Wires in Flexibles with Equivalent Solid Wire S.W.G.

Equivalent Solid Wire S.W.G.	No. 40.	No. 38.	No. 36.	No. 33.	No. 30.	No. 28.	No. 26.
23	25	16	10	—	—	—	—
22	34	22	14	—	—	—	—
21	44	29	18	10	—	—	—
20	56	36	22	13	—	—	—
19	70	45	28	16	10	—	—
18	100	64	40	23	15	11	—
17	136	87	54	31	21	14	10
16	178	114	71	41	27	19	13
15	225	144	90	52	34	24	16
14	278	178	111	64	42	29	20
13	367	235	147	84	55	39	26
12	469	301	187	108	70	49	33

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Table III.

Cable Makers' Association Standard Flexibles.

Number of Wires in Flexibles with Equivalent Cross-sectional Area.

Equivalent Sq. In.	No. 40 S.W.G.	No. 38 S.W.G.	No. 36 S.W.G.	No. 33 S.W.G.	No. 30 S.W.G.	No. 28 S.W.G.	No. 26 S.W.G.
0·010	552	354	220	127	83	58	39
0·015	828	531	330	191	125	87	59
0·020	1,105	708	441	254	166	116	79
0·025	1,380	885	551	318	208	145	98
0·030	1,656	1,062	661	382	249	174	118
0·040	—	1,416	882	509	331	233	157
0·050	—	1,770	1,102	637	414	291	196
0·075	—	—	1,655	955	623	436	295
0·100	—	—	—	1,273	830	581	393
0·150	—	—	—	1,910	1,240	872	589
0·200	—	—	—	—	1,656	1,163	786
0·250	—	—	—	—	—	1,454	982
0·300	—	—	—	—	—	1,744	1,179
0·350	—	—	—	—	—	—	1,375
0·400	—	—	—	—	—	—	1,572
0·450	—	—	—	—	—	—	1,768
0·500	—	—	—	—	—	—	1,964

Conductivity of Small Stranded Conductors.—The following tests were made to determine whether the conductivity of a twisted stranded conductor is the same as that of a solid conductor of equivalent cross-sectional area. The experiments were made with both pure and tinned copper wires as supplied by the cable makers. The diameters of the tinned wires were found to be slightly greater

Table IV.

Diameters of Tinned Copper Wires for Flexibles.

Firm.	Nominal Size S.W.G.	Standard S.W.G. Diameter in Inches.	Diameter of Tinned Wires in Inches.
A	36	0·0076	0·0080
B	36	0·0076	0·0078
D	36	0·0076	0·0085
D	38	0·0060	0·0066

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than their nominal gauges, the wires being drawn to standard gauge and then tinned. The thickness of the tinned coating varied with different samples, as shown in Table IV.

The conductivity of the stranded conductors as determined with the Kelvin double bridge is given in Table V.; as a check on the results the resistance of a single solid conductor No. 18 S.W.G. was measured and compared with the resistance per yard of equivalent solid conductors as given by tables. These results are placed at the bottom of Table V. The resistance tables referred to are in general use and agree with the Engineering Standards Committee's standards for copper conductors.

TABLE V.

Conductivity of Stranded Conductors.

Firm.	Nominal Size in S.W.G.	Copper Conductor.	Measured Res. per Yard of Stranded Conductor.	Res. per Yard Equiv. Solid (from Tables).	Measured Conductivity of Stranded. / Conductivity of Nominal Equivalent Solid.
B	23/36	Tinned	0·02305	0·02305	1·000
B	40/36	"	0·01328	0·01328	1·000
B	35/40	Pure	0·03535	0·03799	1·075
B	70/40	"	0·01780	0·01913	1·075
B	35/38	"	0·02300	0·02429	1·055
B	61/38	"	0·01320	0·01393	1·055
A	23/36	Tinned	0·02284	0·02305	1·010
A	40/36	"	0·01300	0·01328	1·016
A	56/40	Pure	0·02135	0·02362	1·108
A	100/40	"	0·01222	0·01328	1·085
D	27/38	Tinned	0·02877	0·03150	1·095
D	23/36	"	0·02130	0·02305	1·082
					Ratio of Measured to Tabled Conductivity.
	1/18	"	0·01330	0·01328	0·9985

A consideration of Table V. shows that the conductivity of stranded flexibles may be taken as at least equivalent to the standard values for their equivalent solid sections. The comparatively large excess of conductivity shown by some samples is due to the constituent wires being actually larger than their nominal standard gauge. The question of cross conductivity may also affect this result.

Assuming that the current flows not only along the twisted strands of the conductors, but also straight from strand to strand through the lines of contact, the effective conducting cross-sectional area will be

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greater than that of the equivalent solid section of its constituent conductors, and its resistance will therefore be lower. This principle is illustrated in Fig. 3, which represents a rectangular copper bar closely overwound with a second bar of similar section, the conducting area being manifestly much greater than the combined cross-sectional areas of the two bars.

With a lay of 1 in 20, however, it can be shown by calculation that the increase in cross-sectional area is of the order of 0·2 per cent., and against this effect has to be set the increase in resistance due to the increase in length of the conductor. The matter is a difficult one to deal with in the case of flexibles, as the resistance of wires of small diameter is perceptibly increased by bending or winding, and further the errors in measuring the diameter affect the computed areas far more seriously than is the case with larger wires.

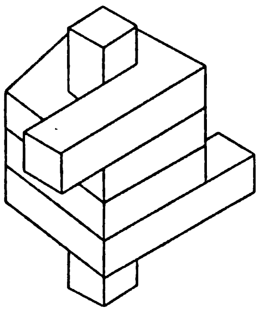

FIG. 3.

This matter is of interest in connection with the tolerance for tinning and lay of conductors, and Mr. A. E. Moore, who kindly carried out these experiments for the author, proposes to extend them to cables of larger sizes, both tinned and untinned. In general the conductors for service with vulcanised rubber are tinned, whereas those for use with taped rubber are not.

There are four causes of weakness in the conductors which would appear to operate in actual practice:—

(1) Extension of the wires by bending when under small loads.
(2) Loss of tenacity due to increase of temperature at the lampholder.
(3) Corrosion of the wires due to sulphur from the vulcanising compound.
(4) Corrosion of the wires due to chemical fumes in the air.

(1) *Extension of the Wires by bending when under small Loads.*—Ercolini * has recently investigated in considerable detail the extension of copper wire when wound and unwound under tension upon cylinders of various diameters. He experimented with copper wire 0·04 cm. (16 mils.) diameter wound upon iron cylinders 1, 2, and 4 cm. diameter respectively under tensions varying from 250 to 3,000 grammes (0·5 to 6·6 lbs.). He found that with successive winding and unwinding the wire stretched as much as 84 per cent. before breaking, and that under a tension which produces an insignificant stretching if applied in the ordinary way.

It would seem probable that this cause would operate in the case

* *Nuovo Cimento*, vol. 11, series 5, 1906, p. 243.

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of flexibles which are repeatedly bent at the lamp-holder or round any surface of small radius. The author has carefully examined the fractured ends of the conductors used in the bending tests described on page 72, in which the flexibles were bent many thousand times through a right angle at their attachment to a lamp-holder, when under a tension of 3 lbs., and has found that the diminution in section was quite local, and only extended for a very short distance from the point of rupture. This may have been due to the sharp character of the bend in question, and also largely to the fact that the wires are twisted together.

(2) *Loss of Tenacity due to Increase of Temperature.*—The percentage diminution of the tenacity of copper with increase of temperature is given in Table VI.

TABLE VI.

Diminution of Tenacity of Copper with Increase of Temperature.

Temperature in Deg. Fahr.	Loss of Tenacity Per Cent.
68	2
138	5
248	10
328	15
418	20
438	22
488	25

The temperature attained in lamp-holders is very much higher than is generally supposed. It is, of course, a very variable quantity, depending, not only upon the heat radiated and conducted from the lamp itself to the holder, but also upon the nature of the contact between the lamp terminal plates and the spring plungers of the holder. The temperatures given in Table VII. were kindly measured for the author by Professor W. W. Haldane Gee and Mr. L. Henshaw. They were obtained by means of a thermojunction on lamps and holders in use at the School of Technology, Manchester. The lamps tested were on 110-volt circuits, and the temperatures were taken in two positions, (1) in the lamp-holder between the lamp contact plates, and (2) just above the cord-grip on the flexible.

A further series of tests to determine the temperature attained in bayonet catch holders for electric radiator lamps was made recently by the author and Mr. A. E. Moore for the Engineering Standards Committee on Electrical Plant Accessories, from which the following results are taken :—

Experiments were first made to ascertain the temperature of the outside of the lamp-holder with two lamps glowing. Each lamp took

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TABLE VII.

Temperatures attained in Lamp-holders on 110-volt Circuit.

Position I. = Between contact plates of lamp in holder.
Position II. = Just above cord-grip.

Nominal Candle-power of Lamp.	A = without Shade. B = Opal or Bell Shade.	Total Temperature in Degrees F. Room Temperature = 60° F.	
		Position I.	Position II.
8	Mean of five experiments, A	113	96
8	Mean of five experiments, B	118	—
16	Mean of three experiments, A	143	103
25	One experiment (old lamp), A	203	160
50	One experiment, B	329	145
45	Tantalum lamp, "Sun" type	135	108
23	Tantalum lamp, Type H	123	88
30	Nernst lamp, 1/4 ampere size	145	114

3·5 amperes, and the temperature was measured by means of a thermometer in contact with the holder and wrapped round with tinfoil. The holder was screened from the direct radiation of the lamps by the structure of the radiator, and the maximum temperature attained was 160° F. With a view to obtaining the actual temperatures attained by the contact plungers a new holder was taken, and the

TABLE VIII.

Temperature of Contact Plungers in B.C. Holders for Radiator Lamps. Adapter substituted for Lamp. Room Temperature 14° C. (57° F.). Plungers Oxidised by being held in Bunsen Flame and also Chemically without Heat.

Current in Amperes.	Maximum Temperature attained. ° C.	° F.
2·0	42	107
3·5 (normal current)	105	221
*4·3 ... ... over	230	415
Solder on junction melted.		
3·8 (plungers oxidised chemically with copper nitrate) ... ... over	230	415
Solder on junction melted.		

* The contacts were examined, and it was found that the action of the plunger springs had been destroyed.

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plungers were oxidised by being held in a Bunsen flame for a few minutes; the temperatures were then taken with a thermojunction. The results given in Table VIII. can only be taken as representing what actually occurred in the particular cases mentioned, as the character of such contact resistances is naturally very variable.

It is probable that the heat of the Bunsen first softened the springs, thus causing a bad contact, which resulted in the complete softening of the springs. The temperature attainable in such a damaged holder may be exceedingly high, owing to arcing at the contacts.

These plunger temperatures are of interest, as the plungers are directly connected to the flexible conductors, and the heat thus carried into the insulation is undoubtedly the cause of many breakdowns in the insulation at the lamp-holder hereinafter referred to, as well as tending to reduce the tenacity of the copper, as shown in Table VI.

3. *Corrosion of the Wires due to Sulphur from the Vulcanising Compound.*—The vulcanising compound is usually put on in two layers, the outer one of which, or "jacket," may contain as much as 10 per cent. of sulphur, while the inner one, which is termed the "separator," may contain as much as 3 to 4 per cent. of sulphur. Then follows a layer of pure rubber tape on the tinned conductors. A reference to Appendix E, which contains a detailed examination of old vulcanised flexibles, shows that in most cases the wires have been blackened by the action of the sulphur, and that in some cases they have been severely injured.

Table IX. shows the percentage reduction in tenacity due to this cause from the experiments of the author and Mr. John Roberts.

The load was applied evenly and at a definite rate by means of a small hydraulic ram. Owing to the varying age of the samples it must not be assumed that the composition of the copper is identical in all cases. Further, it is not improbable that the tin coating which initially existed as a separate covering has diffused into the copper and thus reduced its elasticity.

A consideration of this table shows that the wires insulated with vulcanised rubber have become considerably more brittle than those insulated with pure rubber and within a shorter time.

4. *Corrosion of the Wires due to Chemical Fumes in the Air.*—This is not usually a direct action, particularly in the case of vulcanised rubbers, but takes place in the presence of moisture, which leads first to the deterioration of the insulation, and subsequently to the corrosion of the wires by electrolytic action. In the case of flexibles this action is intensified by the juxtaposition of the conductors and the influence of electric osmosis.

Gymp Flexible.—This is a special flexible which was brought to the author's notice by Mr. Mervyn O'Gorman. Owing to the structure of the conductors it possesses an extraordinary degree of flexibility, and its performance in this respect is referred to under the head of Tests on Completed Flexibles (see page 69). The conductors are composed of flat copper strips, 10 mils. wide and 1·5 mils. thick. These strips are

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TABLE IX.

Tensile Strength of Conductors of Old Flexibles Insulated with Pure and Vulcanised Rubber and with Cotton. Length of Test Piece, 7 ins.

Sample. Reference Number.	Sample. Age in Years.	Diameter of Wire in mm.	Breaking Load in Grammes per sq. mm.	Percentage Extension on Rupture.	Nature of Insulation.
E. 31	7	0·160	18,800	18·3	Pure rubber.
E. 34	20	0·134	17,600	17·2	"
E. 36	10	0·162	20,500	20·7	"
E. 11	14	0·135	18,350	19·5	"
E. 9	22	0·135	23,150	17·0	"
E. 10	18	0·134	19,350	24·0	"
E. 13	16	0·126	20,000	14·3	Cotton only.
E. 42	6	0·150	20,300	10·3	V.I.R.
E. 17	7	0·159	20,900	11·5	"
E. 8	8	0·134	14,200	0·9	"
E. 41	8	0·134	20,350	10·0	"
No. 40, S.W.G. New copper wire, untinned		0·125	24,900	24·5	—
No. 36. New copper wire, tinned ...		0·195	24,150	24·9	—
Ditto		0·200	24,180	26·3	—

NOTE.—The breaking load per sq. mm. is calculated on the measured diameter of the wires, and therefore includes the tinning.

each wound in a close spiral around a separate silk core, and twenty-one of these are then stranded together in sets of seven to form the complete conductor. The resistance of such a conductor is naturally high, that of the small specimen submitted to the author after it had run 1¼ million times over a counterweight pulley being 1·72 ohms per yard of double conductor.

In general the question of conductivity of flexibles as applied to pendants, etc., may be considered as being overridden by the requirements of mechanical strength, which will dictate the minimum section to be employed, but the conductivity is of considerable importance in connection with the use of flexibles for wiring systems.

III. HEATING OF CONDUCTORS DUE TO EXCESSIVE CURRENTS.

This matter is of interest in connection with the temperatures attained with flexibles due to short-circuit currents and the employment of heavy fuses on sub-circuits.

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A series of experiments was made by the author and Messrs. F. Shaw and J. Davies on (1) the temperatures attained in a given time with bare conductors with various currents, (2) the corresponding temperature rises with the same conductor when insulated. The results of these experiments are shown graphically in Figs. 4 and 5. As is to be expected, the temperature rise in a bare wire with a given current is higher than that of the same wire when insulated. The currents selected were purposely large in order that the kindling point of the insulation might be reached. It is to be noted that in Fig. 4 the conductor was only covered by the insulation, there being no braiding or

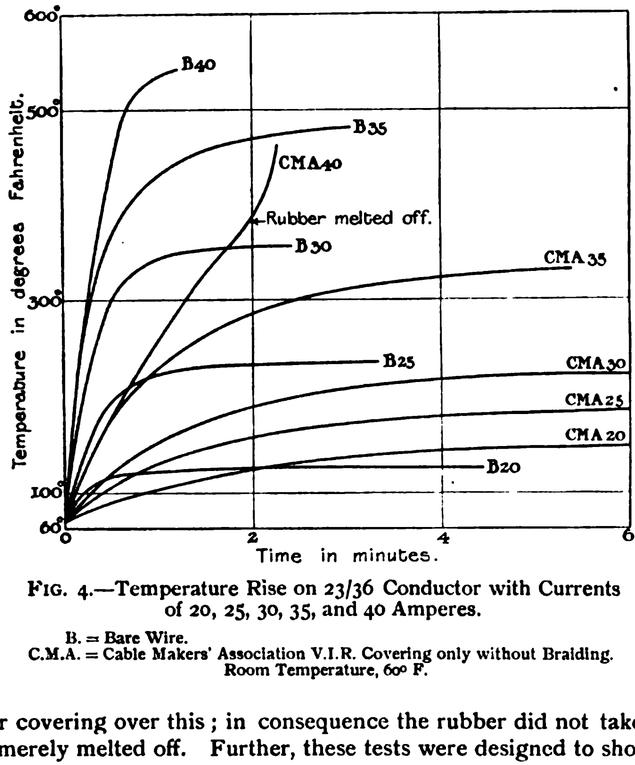

FIG. 4.—Temperature Rise on 23/36 Conductor with Currents of 20, 25, 30, 35, and 40 Amperes.

B. = Bare Wire.
C.M.A. = Cable Makers' Association V.I.R. Covering only without Braiding.
Room Temperature, 60° F.

other covering over this; in consequence the rubber did not take fire, but merely melted off. Further, these tests were designed to show the temperatures attained with comparatively large currents of short duration, and they must not be taken as indicating the temperatures attainable with the currents named if kept on continuously.

Fig. 5 shows the relative temperature rise on a 23/36 conductor with a given current when made up in different forms. A consideration of these curves shows that there is not much to choose between the various finishes tested as to their radiating capacity.

A further series of experiments was carried out with the same size of conductor in various finishes but with heavier currents, with a view to

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finding the kindling point of the insulation. The results are given in Table X. They are remarkable in that with one exception they show that the vulcanised rubber insulation actually burst into flame only when the conductor fused. This is doubtless due to the firing of the inflammable vapours by the arc following the fusion of the conductors, and it is rather an unfortunate property from a fire risk point of

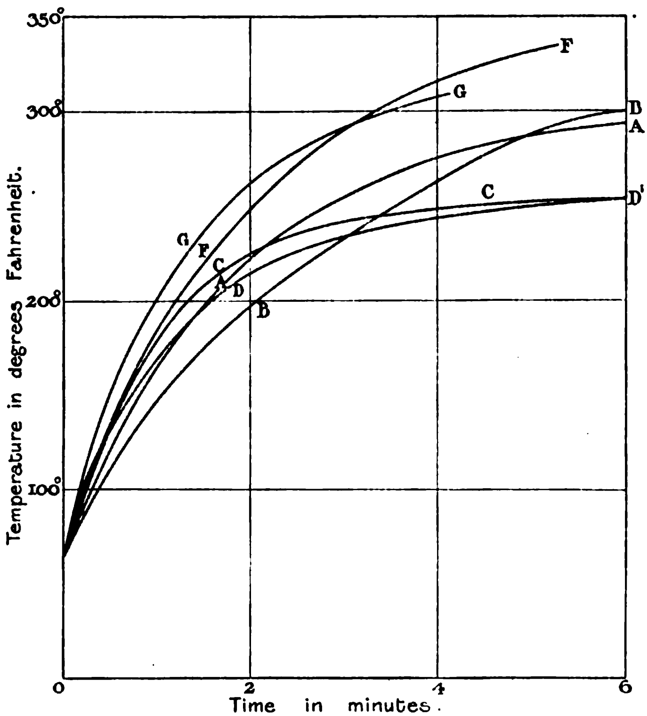

FIG. 5.—Temperature Rise on 23/36 Conductor in various Finishes with a Current of 30 Amperes.

A = C.M.A. Twin-twisted Glacé.
B = C.M.A. Workshop.
C = C.M.A. same as A, but Single Conductor.
D = C.M.A. Twin-twisted Silk.
F = Double Pure Rubber Twin-twisted.
G = Single Pure Rubber Twin-twisted.

view, as it may start the fire from two centres, one on the floor beneath and the other on the ceiling above. Flexibles insulated with pure rubber ignite before the wire fuses. The proportion of rubber in vulcanised indiarubber compound is comparatively small, and the mineral loading matter evidently delays the ignition.

These experiments were for obvious reasons conducted in a fume chamber, where the air was comparatively still, and it is possible that

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in a strong current of air the ignition of the vulcanised indiarubber might take place before the fusion of the wire; but the general result, that in still air the insulation will give off heavy fumes but will only smoulder and char while the conductor remains intact, is supported by the fact that the persistent arcs which have already been referred to travel up these wires without flaming.

Table X.

Kindling Points of Flexibles.

The Times given are from the Moment of Switching on the Current. With Currents of 40, 50, 60, and 70 Amperes. Time in Minutes and Seconds.

A. Insulated with Vulcanised Rubber.

Condition of Insulation.	C = 40. Min. Sec.	C = 50. Min. Sec.	C = 60. Min. Sec.	C = 70. Min. Sec.	Description of Flexible.
Smoking	1 55	0 40	—	—	Twin-twisted 23/36 C.M.A.
Insulation melting out	3 0	1 20	0 40	0 30	
Dense fumes ...	5 0	1 45	1 0	0 35	
Material red hot ...	6 0	2 0	1 3	0 44	
Fused ... ... Flamed	7 5	2 28 2 25	1 30	1 1	
Smoking	4 0	1 30	0 35	—	Workshop 23/36 C.M.A.
Insulation melting out	4 30	1 45	0 40	—	
Dense fumes ...	6 0	2 20	1 15	—	
Material red hot ...	8 40	2 50	1 30	—	
Fused and flamed	8 45	3 20	1 40	—	

B. Insulated with Pure Rubber.

Condition of Insulation.	C = 40. Min. Sec.	C = 50. Min. Sec.	C = 60. Min. Sec.	C = 70. Min. Sec.	Description of Flexible.
Smoking	1 25	0 40	0 20	0 10	Twin-twisted 23/36 single pure rubber.
Dense fumes ...	1 40	0 50	0 25	0 20	
Material red hot ...	2 10	1 5	0 35	0 30	
Flamed	2 18	1 10	0 40	0 33	
Wire did not fuse	5 0	—	—	—	
Wire fused ...	—	1 15	0 45	0 36	
Smoking	2 0	1 10	0 35	0 15	Twin-twisted 23/36 double pure rubber.
Dense fumes ...	2 30	1 15	0 40	0 25	
Material red hot ...	3 20	1 30	0 50	0 40	
Flamed	3 40	1 50	1 0	0 45	
Wire fused ...	—	2 0	1 5	0 47	
Wire did not fuse	6 0	—	—	—	

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IV. Insulation of Flexibles.

Before dealing in detail with the insulation of flexibles it will be well to consider briefly the prominent characteristics of the materials employed. This procedure is doubly desirable, first on account of the secrecy observed with regard to rubber manufacture, which entails an almost complete ignorance on the part of the average electrical engineer of the character of this important material, and secondly because it is necessary that those who are actively concerned with the employment of the material in practice should be in a position to judge for themselves of the results of tests that may be submitted to them or which they may specify or carry out.

Pure Rubber Strip.—The pure rubber strip which is used for insulation purposes is prepared by two distinct methods, and is known as "cut" or "spread" sheet, according to its mode of manufacture.

The raw material is the same in either case, and is first washed and dried. In the preparation of "cut" strip the dried rubber is, after being passed through compression rollers, put through a "masticator" and then formed into blocks under considerable pressure. These blocks are frozen hard and then cut into sheets by special machinery. The process outlined above is necessarily expensive, and is only followed by a few firms in this country.

The manufacture of "spread" sheet is much simpler and less costly. The dried rubber is made into a paste or "dough" by means of a solvent and is then spread on to a length of cloth. The solvent is then driven off by heat, leaving the rubber in the form of a sheet, which is then cut into strip.

On the Continent, owing to the cost of fine Para rubber, foreign material is added with a view to producing a cheap article which is put on the market as second or third quality sheet. "Cut" strip is generallv used in this country for the innermost layer in high-class cable work, while "spread" strip is very largely used for rubber-taped flexibles, insulating tape, etc.

The "spread" sheet should, in order to have the requisite mechanical and electrical properties, be "aged" by hanging in a dark room for several months.

The strip may be artificially aged or cold vulcanised by treating the surface with a solution of chloride of sulphur in carbon bisulphide. As rubber tape is often used next to the copper conductors it is important that it should not contain sulphur. This cold vulcanised strip not only contains sulphur but nearly always contains hydrochloric acid as the result of its chemical treatment.*

Pure rubber has a great affinity for oxygen, and if placed in direct contact with copper, the latter will part with any oxygen it has to the rubber; it is therefore quite necessary that the wires should be tinned or at least covered with a close wind of cotton when in contact with pure rubber.

* Atkinson and Beaver, "Some Points on the Selection of Electric Light Cables.' Manchester Local Section, I.E.E., 1905; *Electrician*, vol. 54, p. 702.

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Absorption of Water by Indiarubber.—The classic experiment of Thomas Hancock, which extended over a period of thirty years—from 1826 to 1856—showed that water hermetically sealed in a rubber bag is capable at ordinary atmospheric pressure of passing through rubber, the whole of the water contained in the bag—rather more than 12 oz.—having disappeared in that time.

Indiarubber will absorb about 25 per cent. by weight on prolonged immersion in water with considerable increase in volume.

The amount of water absorbed is a very variable quantity, and depends very largely on the amount of oily and resinous matter contained in the rubber and also on the treatment that its surface has received.

This question is of importance in connection with flexibles insulated with pure rubber, particularly as under the action of electric osmosis the moisture of the positive conductor may be driven over and forced into the negative insulation.

Vulcanised rubber is much more homogeneous in structure than pure rubber, and the amount of water absorbed is, in consequence, very much less, but nevertheless the fact that it does absorb water must not be ignored. A reference to the Appendices A, B, and C at the end of the paper will show that immersion tests for flexibles are required in the United States (A. 2*d*), in Germany (C. 2*d*), and in France (B. 1*c*).

The insulation resistance after immersion in water may be taken as an indication of the amount of absorption of water by V.I.R. flexibles, but can hardly be so taken when pure rubber tape is employed, as the water may enter between the joints. A well-made pure rubber flexible will stand immersion in water without actually breaking down for a much longer period than is generally supposed. Mr. Lester Taylor informed the author that he had a short length immersed in water which supplied current to a 100-volt lamp for several months without breakdown. The following tests were made on vulcanised (600 megohm grade) and double pure rubber (2,000 megohm grade), supplied by Firm C, immersed in water for a week at 60° F.

Double pure rubber. Test pressure, 550 volts.

Insulation between conductors: In air, 6,000 megohms; after one week in water at 60° F., 40,000 ohms.

On immersion in water the insulation fell almost at once to 80 megohms, and thence slowly declined and broke down in eight days with 400 volts. This test was on a length of only 10 yards.

Vulcanised rubber. Result of immersion inappreciable on 10-yard length.

Vulcanised Rubber.—Of all the constituents of manufactured indiarubber none possess such a paramount influence upon the general excellence of the product as the sulphur of vulcanisation. The amount of sulphur employed in practice varies greatly from 4 up to 50 per cent., but the amount of sulphur fixed by the indiarubber (sulphur of vulcanisation) very rarely exceeds 3 per cent. in commercial rubber articles, and is generally less. Free sulphur in various proportions

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always forms a constituent of ordinary vulcanised indiarubber goods. C. O. Weber* states that the percentage of combined sulphur is no measure of its degree of vulcanisation, and instances the following analysis of the outer cover of a tire:—

Indiarubber	54·70	per cent.
Organic extract	1·34	"
Sulphur of vulcanisation	1·99	"
Free sulphur	2·88	"
Total mineral matter	41·08	"

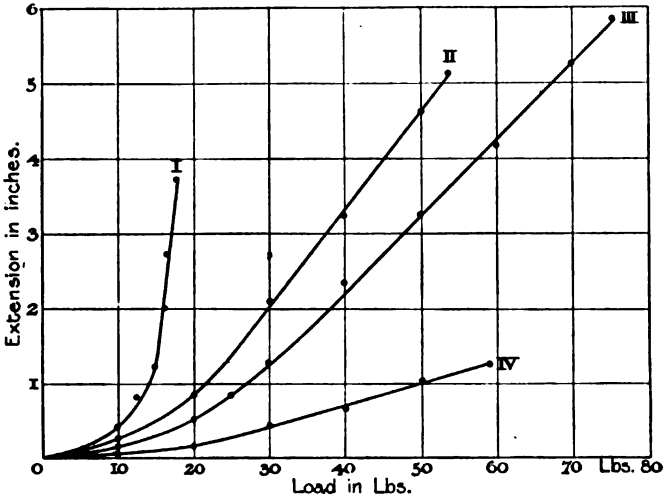

FIG. 6.—Tensile Strength of Differently Vulcanised Specimens of Para Rubber.

SAMPLE.	VULCANISATION COEFFICIENT.
I.	1·78 per cent.
II.	2·14 "
III.	2·87 "
IV.	4·44 "

He obtains the degree of vulcanisation by calculating the percentage ratio between the amount of indiarubber and sulphur of vulcanisation present. Thus from the above analysis—

$$\text{Coefficient of vulcanisation} = \frac{1·99 \times 100}{54·7} = 3·63 \text{ per cent.}$$

As the coefficient of vulcanisation is increased, the tensile strength, elasticity, and distensibility are up to a certain point also increased; beyond this point there is first a rather rapid decrease in elasticity and distensibility, followed soon by a decrease of tensile strength. Fig. 6

* "The Chemistry of Indiarubber," London, 1902, p. 283.

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(C. O. Weber) shows the elongation and tensile strength of four tire covers of absolutely identical composition as regards the quality and proportions of Para rubber, total sulphur, and mineral matter, but cured under different conditions.

Of these samples I. and II. are under-vulcanised, III. is satisfactory, while IV. is over-vulcanised. It will be seen from a consideration of Fig. 6 that the higher the coefficient of vulcanisation the higher is the tensile strength for the same elongation. The results given are typical for Para rubber.

Over-vulcanisation does not consist simply in a high coefficient of vulcanisation, but in one obtained under unsuitable conditions, either

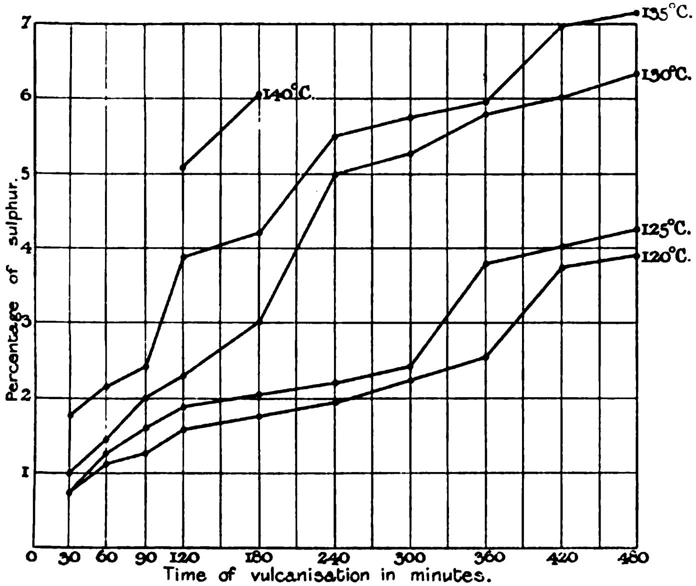

FIG. 7.—Vulcanisation Curves of Para Rubber at Different Temperatures.

of temperature, or of time, or of quantity of sulphur. Of these causes too high a temperature is the commonest one, while too short a time is the most usual cause of under-vulcanisation. Flexibles as a rule are slightly under-vulcanised, as it is found that a few minutes more or less in the vulcanising chamber may make the difference between a bright or blackened conductor.

The rate at which the sulphur enters into combination with the indiarubber hydrocarbon (polyprene) is characteristic for each brand of rubber. Fig. 7 (C. O. Weber) shows the vulcanisation curves for Para rubber.

The experiments were carried out with strips cut from a calendered sheet 3 mm. in thickness from a mixing of 100 parts of Para rubber

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with 10 parts of pure precipitated sulphur. After vulcanisation in a digester the samples were freed from every trace of uncombined sulphur by extraction with acetone in a Soxhlet extractor, and the sulphur of vulcanisation subsequently ascertained by analysis. This point is of interest in connection with the high temperatures attained in lamp-holders and the possibility of the free sulphur present entering into combination with the rubber and producing an over-vulcanised covering.

V. Oxidation of Rubber.

The formation of resinous bodies from unvulcanised rubber on exposure to the air was first observed by Spiller.* These oxidation products are known as Spiller's resin. Burghardt† states that the amount of oxygen taken up or combined with the rubber is an index of the amount of deterioration which it has undergone, and quotes the analysis given in Table XI. in support of this view.

Table XI. (Burghardt).

Oxidation of Rubber as an Index to Deterioration.

	Sample Number.				
	1.	2.	3.	4.	5.
Carbon	87·27	87·50	77·91	72·53	64·00
Hydrogen ...	12·73	10·00	10·33	11·31	9·26
Sulphur	Nil	2·50	5·12	1·97	2·28
Oxygen	Nil	Nil	6·61	14·19	24·46

No. 1. Pure caoutchouc from Para.
No. 2. Theoretically vulcanised elastic thread.
No. 3. Vulcanised elastic thread perfectly sound.
No. 4. Vulcanised elastic thread damaged, but still elastic.
No. 5. Vulcanised elastic thread brittle and very hard.

Thomson,‡ who investigated the subject, further observed marked oxidation, especially at higher temperatures.

A consideration of Appendix D, which contains a detailed examination of samples of flexibles which have been in use for a number of years, shows that the vulcanised rubbers seem to have suffered most, but that the pure rubber also has in many cases perished considerably. This perishing, due to oxidation, although it no doubt

* *Journal of the Chemical Society*, vol. 3 (new series), 1865, p. 44.
† "Thorpe's Dictionary of Applied Chemistry," vol. 2, p. 320.
‡ *Journal of the Society of Chemical Industry*, vol. 4, 1885, p. 710.

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takes place more rapidly in the high temperatures in the immediate vicinity of the lamp-holder, and to a lesser degree at the ceiling rose also, affects the whole of the cord, and in the author's view puts a limit of from ten to twelve years as the safe life of an average flexible of good quality under favourable circumstances. The use of oxidised oil, recovered rubber, and other rubber substitutes will shorten the life of the flexible in proportion to the quantities of these substitutes that are present.

There is no doubt that oxidation plays a prominent part in the deterioration of flexibles in warm situations, and it would be interesting to know if the "reinforced cord" used in the United States—consisting of a filling of rubber or bitumen which makes up the cord to circular form and completely encloses the insulated conductors—conduces to the longer life of the actual insulation by excluding the oxygen.

Recovered Rubber.—Recovered rubber undergoes vulcanisation just like fresh rubber, but it is not devulcanised by the recovery process; indeed, the sulphur of vulcanisation is increased rather than lessened. Consequently samples containing a large percentage of recovered rubber have usually a high coefficient of vulcanisation, so that if the hysteresis loops (Figs. 10–13) or the elongation tests do not point to over-vulcanisation, this high coefficient may usually be taken as indicating the presence of recovered rubber. This is not always the case, as the recovered rubber may have been prepared from articles having a low coefficient of vulcanisation.

VI. Effect of High Temperature on Rubber.

The high temperatures attainable in lamp-holders have already been discussed. Under the influence of high temperature rubber develops many defects, of which the following are the chief :—

(1) *Loss of strength or cohesion.*
Rubber with a comparatively low coefficient of vulcanisation is liable to develop this defect, particularly if the time for vulcanisation has been short, as is not unusually the case with flexibles.

(2) *Hardening with brittleness.*
This defect appears in rubbers containing white substitutes (chlorosulphides), but more commonly is due to the presence of a considerable amount of free sulphur.

(3) *Stickiness and darkening in colour.*
This defect is associated with rubbers containing mineral oils, large quantities of recovered rubber, or large proportions of sulphide substitutes.

In order to test the effect of high temperature on pure and vulcanised rubbers, the following experiments were carried out by the author and Messrs. Roberts and Davies. A number of samples of vulcanised rubber were cut from wire supplied by Firm D. These

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were about 3 ins. long, and were placed in an electrically heated oven and kept continuously at a temperature of 100 to 105° C. Three samples were withdrawn each day, and tested, for breaking load and extension. As may be anticipated, it was found that the pure rubber was quite unable to withstand this temperature, and melted. The vulcanised rubber rapidly deteriorated both in tensile strength and percentage elongation. The results of these tests are shown graphically in Figs. 8 and 9.

A further series of deterioration tests on C.M.A. vulcanised rubber was carried out at 100° F., but did not yield consistent results. The tests were therefore repeated at 150° F., and the results are shown

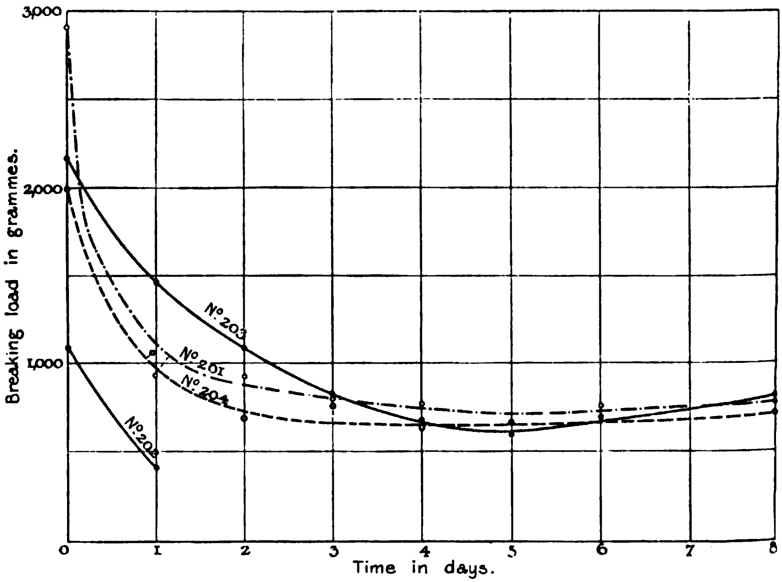

FIG. 8.—Effect of Heat on Tensile Strength of Vulcanised Rubber.
Reference No. 201-4. Heated in Air for 8 Days at 100-105° C. Length of Test Piece, 1·8 cms.

graphically in Fig. 9A, the points plotted being in each case the mean of three experiments. The rise in Curve A is curious; it was found that this same material, when sealed up in glass tubes filled with carbon dioxide and maintained at 150° F., had at the end of four days a percentage extension of 550 as against an initial value of 450, while at the end of twelve days it had only fallen to 400, and throughout the test the breaking stress remained constant at 960 lbs. per square inch. Firm C's samples (see Curves C and D, Fig. 9A) when heated in carbon dioxide under the above-mentioned conditions had an initial breaking stress of 1,280 lbs. per square inch, which fell at the end of twelve days to 960 lbs., and in the same period the percentage extension decreased from 500 to 400. In these cases three experiments were made for each

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point, and gave very consistent results, but a fuller knowledge of the constituents of the compounds is required to interpret them correctly. A consideration of Curves in Figs. 8, 9, and 9A, together with the results of heating in carbon dioxide, would appear to indicate that:—

(1) The greater part of the deterioration is due to oxidation.
(2) A certain amount of deterioration goes on in the absence of oxygen, and possibly some change in the state of the vulcanisation may take place.

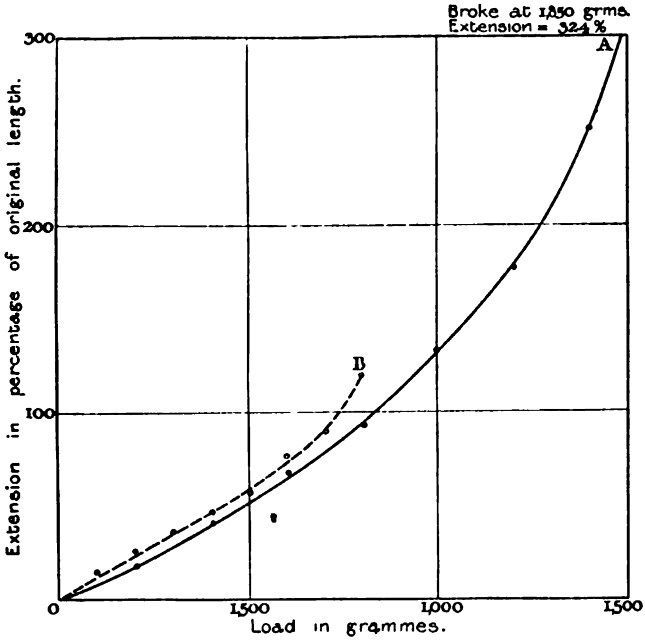

FIG. 9.—Effect of Heat on Vulcanised Rubber.

Reference No. 203. Curve A, Percentage Extension of New Sample at 60° F. Curve B, Extension of Sample of Same Material after Heating in Air at 100° C. for 8 Days.

(3) Although the rate of deterioration is fairly constant over a considerable period, it would be advisable to extend the dry heat test over a longer period than one hour, which is the present practice.
(4) An extension test after a period of heating at 150° F. is desirable to discriminate as to the probable durability of the materials employed.

The question as to which of the two classes of rubber gives the best results in such a high temperature is a debatable one. The author favours the view that pure rubber is best suited for high temperatures,

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since if it does soften and melt, it is absorbed by the cotton surrounding it, whereas in the case of vulcanised rubber it becomes hard and friable and disintegrates on bending.

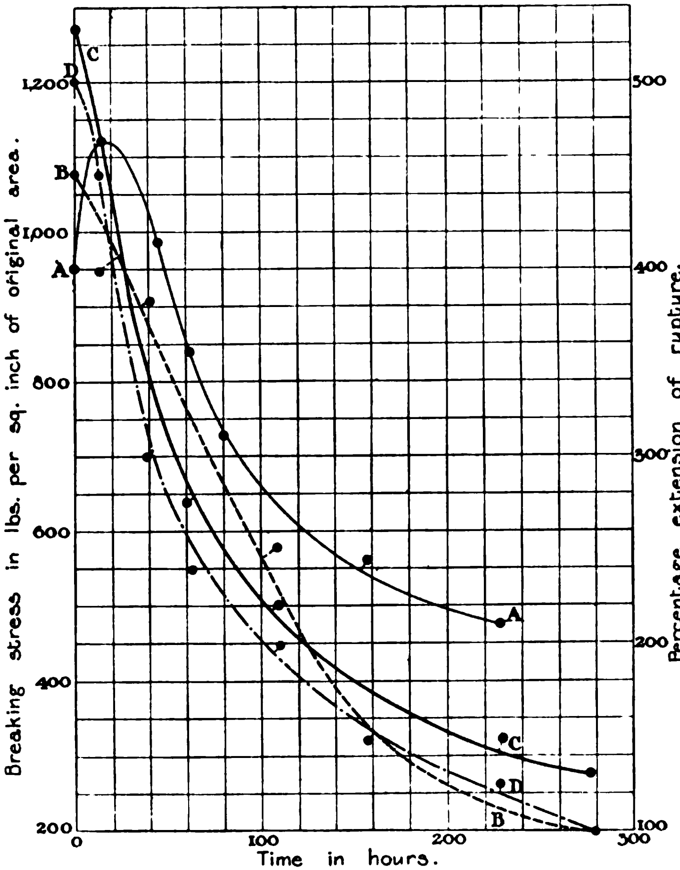

FIG. 9A.—Effect of Heating Vulcanised Rubber at 150° F.

Curve A, Breaking Stress C.M.A. Flexible, Firm D.
„ B, Percent. Extension „ „ „
„ C, Breaking Stress „ „ Firm C.
„ D, Percent. Extension „ „ „

VII. Hysteresis of Rubber.

J. C. Shedd and R. L. Ingersol,* experimenting with rubber bands, found on gradual stretching and releasing that if the extensions and retractions are plotted on a base of load, a complete hysteresis loop is

* *Physical Review*, vol. 19, 1904, p. 107.

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obtained. They investigated the elastic limit of rubber, but the data attached to their curves are incomplete, so they are not reproduced here.

The following experiments on the mechanical hysteresis effect in pure and vulcanised rubbers were carried out by the author and Mr. R. K. Keer. The rubber to be tested was in the form of strip,

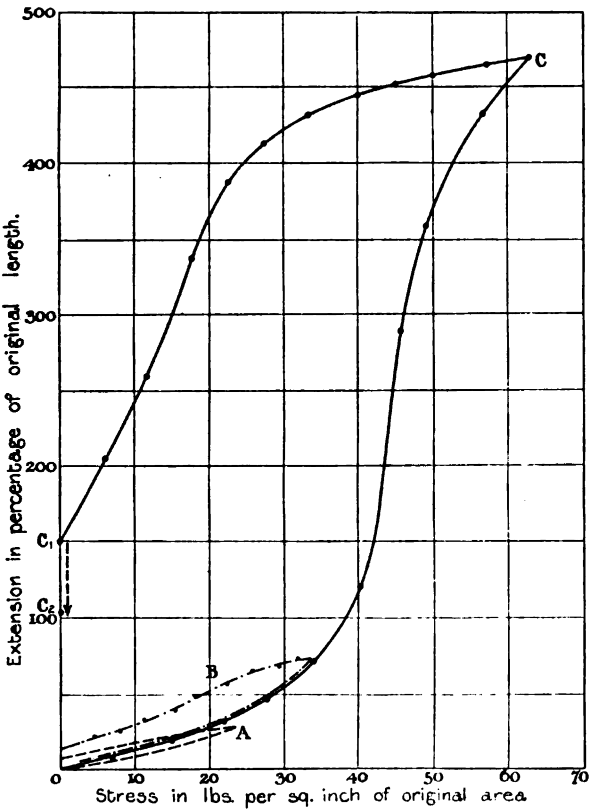

FIG. 10.—Hysteresis Curves for Pure Spread Rubber Sheet.
Width, 0·71 in. Thickness, 0·025 in.

A. Length, 7·88 ins. Time between applying Load and taking Reading = 30 seconds.
B. " 7·88 " " " " " " " = 2 minutes.
C. " 1·97 " " " " " " " = 2 "

and was suspended from a clip and loaded directly by means of weights; the length between two marked points was measured on a vertical glass scale behind the rubber. Throughout the experiments the room temperature was 61° F.

Tests were first made on commercial pure rubber strip, as used for insulating purposes; this strip is prepared by the spreading method.

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The results are shown graphically in Fig. 10. Curve A was obtained on a 20-cm. length, the readings of the extensions being taken thirty seconds after adding or subtracting the loads. Curve B was obtained on the same piece of rubber used for Curve A, the readings in this case being taken after a lapse of two minutes; the load also was carried to a higher value. It is evident from a consideration of these curves that with low loads the hysteresis effect is small, and that the time (between the limits named) allowed to elapse between the alteration of the load and the reading of the extensions does not affect the results to any great extent. With large loads, however, this time lapse is very important, as the rubber flows considerably. In all the following

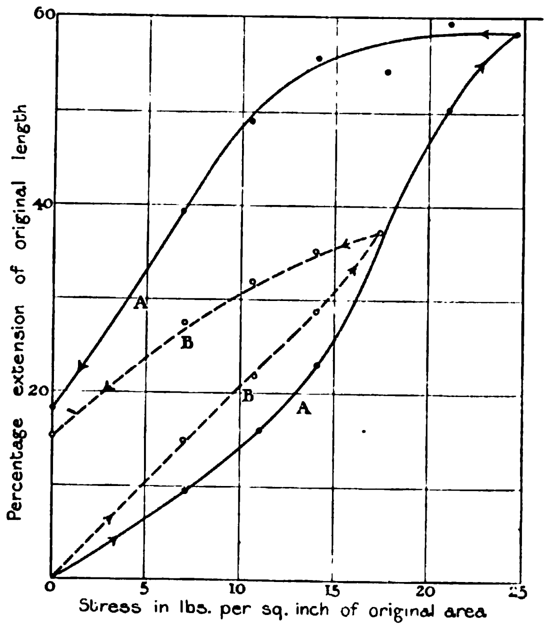

FIG. 11.—Hysteresis Curves for Pure "Cut" Rubber Strip. Width, 0·39 in. Thickness, 0·036 in.

A. Length, 0·39 in. Tested with the Grain.
B. " 1·97 " " across " "
Room Temperature, 60° F.

experiments a two-minute interval was allowed. Curve C, Fig. 10, shows the loop obtained with strip of the same dimensions as in A and B, but with the stress increased nearly to the breaking-point of the rubber. The ordinate OC_1 represents the "permanent" set in the rubber. This is really a very variable quantity, as rubber possesses considerable power of recovery; in this instance OC_2 represents its value after a lapse of sixteen hours.

Fig. 11 shows the results obtained with "cut" strip. This material

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possesses very different tensile strength according as it is tested with the grain or across the grain, the "grain" being due to saw marks in cutting. Curve A is for "with the grain" and B for "across the grain."

Experiments were made on C.M.A. vulcanised rubber stripped from flexibles supplied by four separate firms.

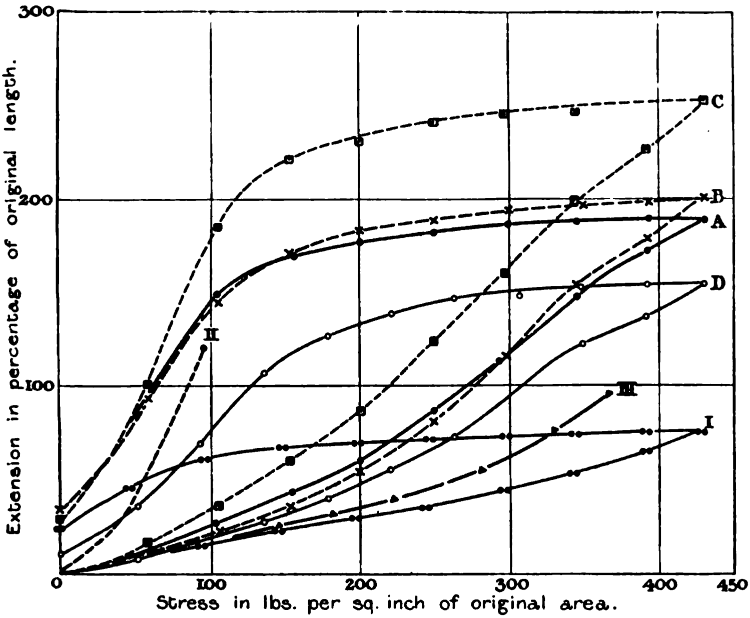

FIG. 12.—Hysteresis Loops for C.M.A. Flexibles 40/36.

A = Firm A, Breaking Load 590 lbs. per sq. inch. % Extension on Rupture 375.
B = ,, B ,, ,, 440 ,, ,, ,, ,, ,, ,, ,, 325.
C = ,, C ,, ,, 440 ,, ,, ,, ,, ,, ,, ,, 325.
D = ,, D ,, ,, 650 ,, ,, ,, ,, ,, ,, ,, 366.

Samples sold as being equal to C.M.A. Insulation (I.) and Non-Association Wire (II. and III.) :—

I. Breaking Load 540 lbs. per sq. inch. % Extension on Rupture 129.
II. ,, ,, 140 ,, ,, ,, ,, ,, ,, ,, 162.
III. ,, ,, 370 ,, ,, ,, ,, ,, ,, ,, 91.

NOTE.—The Percentage Extensions on Rupture are worked out from results given in Appendix D for C.M.A. Flexible in which a 12-in. length was stretched to the breaking-point in about 2 minutes. The Extension on Samples I. to III. was measured in the same way.

In all three cases the insulation consisted of—

(1) Pure rubber.
(2) Rubber separator.
(3) Vulcanised rubber.

The thickness of these layers and their composition appear to vary in the three makes. As, however, the load is plotted in pounds per square

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inch, calculated from the actual loads and the initial areas of the strips, the test is on a common basis as far as dimensions are concerned. The results are shown graphically in Fig. 12, together with the results for material purporting to be of equal quality to C.M.A., but which an analysis showed to be composed of low-grade ingredients. Fig. 13 shows a set of similar curves for American "Code" wire.

Through the kind co-operation of one of the firms supplying samples, the author was furnished with a series of strips of jacket and separator compound containing definite percentages of rubber and

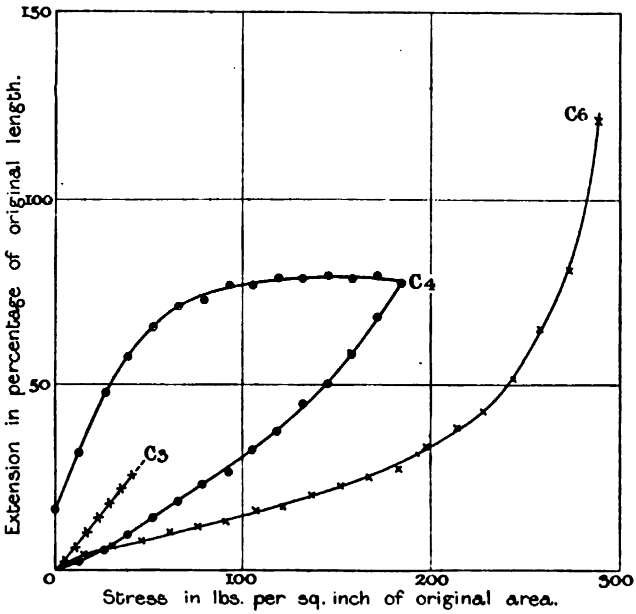

FIG. 13—Hysteresis Loops of American "Code" Wire.

C_3, Old Code Length. Broke at 48 lbs. per sq. inch.
C_4, New Code (insulation in form of tube 1 in. long).
C_6, Old Code (insulation in form of tube 1 in. long). Broke at 304 lbs. per sq. inch.

vulcanised in the same way. The other ingredients of the compound were varied according to the experience of the manufacturer, in order to produce the best results for each per cent. of rubber.

These samples were tested by the hysteresis method and the results given in Fig. 14, curves A and B are plotted on a base of per cent. of breaking load, each sample being stressed up to 70 per cent. of its breaking load. The loops plotted in this way do not place these samples in the order of their rubber contents; a reference to the tables beneath, however, shows that C/D the coefficient of extension and F/D the coefficient of retraction place the samples in the proper order. Curves C and D, Fig. 15, show the retraction and extension curves respectively for the jacket compound plotted on a base of actual load,

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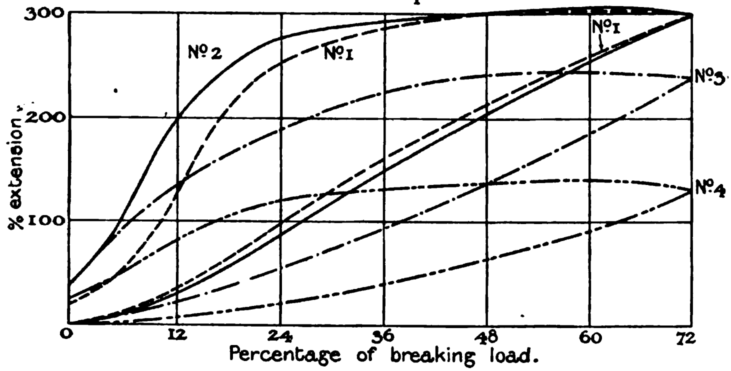
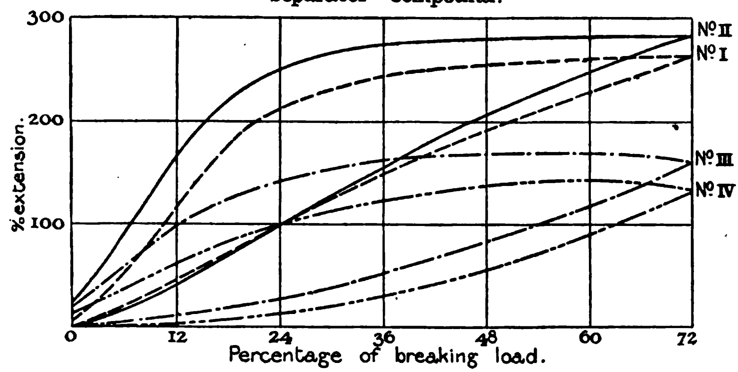
Curve A
Jacket compound.



A	B	C	D	E	C/D	F	F/D
1	60	304	442	632	0·68	290	0·65
2	53	303	678	967	0·44	270	0·40
3	40	248	613	876	0·40	220	0·35
4	35	144	406	580	0·35	120	0·29

Curve B
Separator compound.



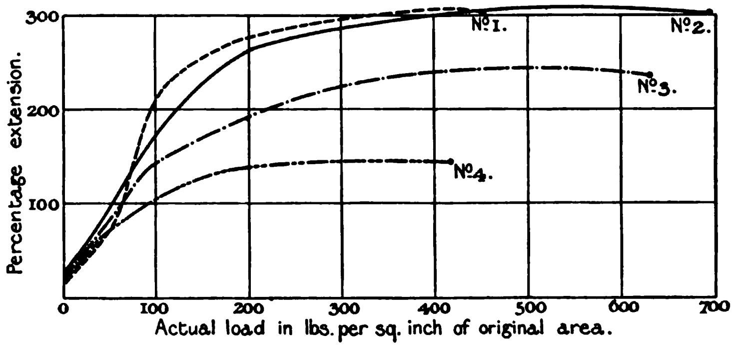
A	B	C	D	E	C/D	F	F/D
I	55	246	406	580	0·65	260	0·64
II	48	292	721	1,030	0·40	264	0·38
III	40	183	514	735	0·35	150	0·29
IV	35	123	542	775	0·22	108	0·19

FIG. 14.

Considering curve D, Fig. 15, and assuming the dotted curve No. 1 as representing the standard, there is no difficulty in placing the other samples in their order of merit.

Curve E, Fig. 16, shows the decrease in the extension of rupture after heating at 150° F. for ten days. This again places the samples in the order of their rubber contents, but the breaking-load curve F under similar conditions does not do so.

Retraction curve C obtained from curve A.



Extension curve D obtained from curve A.

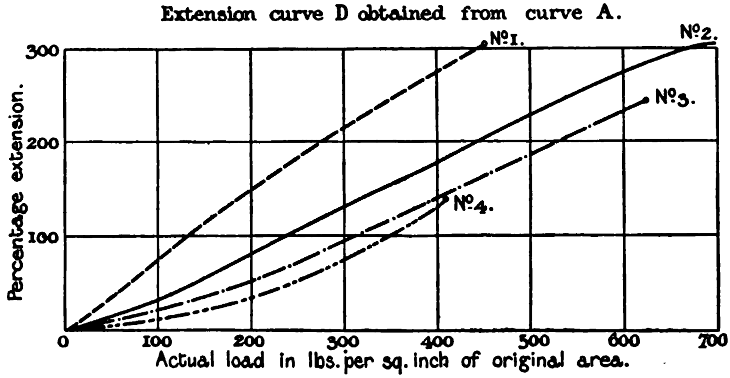


FIG. 15.

The author recognises that a great deal more work will have to be done on the stretching of rubber before the significance of these tests and their limitations are fully understood, but he suggests that by arrangement with the Cable Makers' Association a standard hysteresis loop might be arrived at for given grades of insulation. Such standard loops would to a very considerable extent serve as vulcanisation standards, and would secure the necessary physical properties of the material which give an indication of its durability, while they

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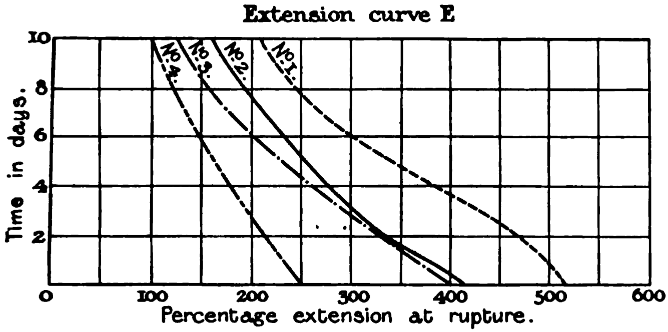
would further undoubtedly conduce to uniformity of manufacture. The apparatus required is simple and inexpensive, and the test is quite easy to carry out.

With regard to the relative merits of the hysteresis method, and the measurement of the permanent set on a sample that has been stretched a given length for a certain number of hours, the hysteresis test is certainly more trouble to carry out, but the results are available in



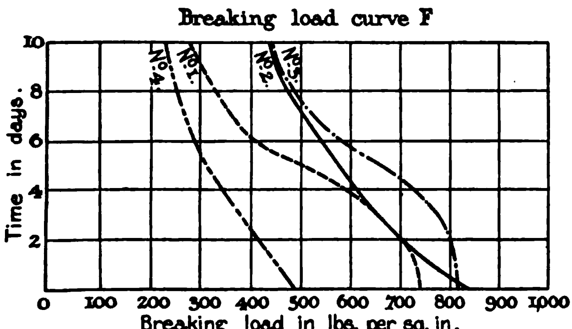


FIG. 16.

a much shorter time, and further, all the conditions of the test may be easily defined, whereas with the elongation test a good deal depends upon the rate at which the rubber is initially stretched as to its subsequent behaviour. Much more information is obtainable from the hysteresis test than from the other; for instance, the amount of extension under small loads and large loads, which gives a good indication as to the state of vulcanisation of the sample, the amount of recovery as the load is removed, and at the end of the test the amount of permanent set can be measured as in the elongation test.

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VIII. The Stretching of Rubber.

Apart from the hysteresis test, the stretching of rubber in the author's view forms one of the best guides as to its quality at the outset, and also affords an indication as to its probable lasting qualities.

It is curious that with the single exception of the test for Para

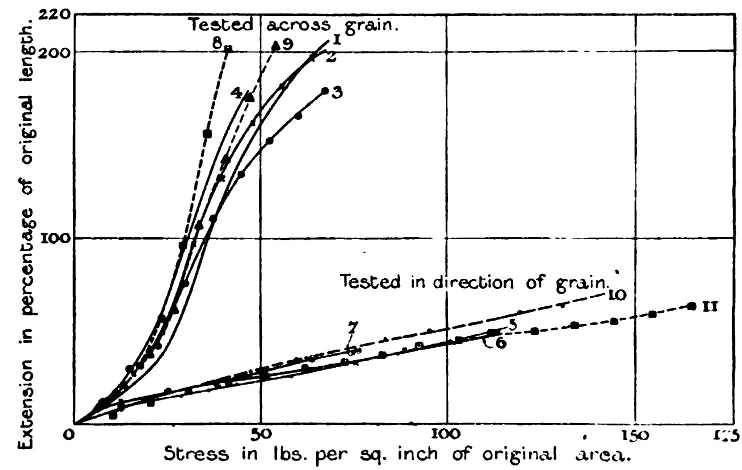

FIG. 17.—Effect of Dimensions of Test Piece.
"*Cut*" Rubber Strip, Length 2 ins.

	Thickness in Inches.	Width in Inches.	Breaking Stress in Lbs. per sq. in. of Original Area.	
1	0·03	0·22	76	Tested across Grain.
2	,,	0·42	71·5	
3	,,	0·89	75	
4	,,	1·29	54·4	
5	,,	0·23	130·5	Tested in direction of Grain.
6	,,	0·53	126	
7	,,	1·05	89	
8	0·018	0·19	46·8	Tested across Grain
9	,,	0·41	60·8	
10	,,	0·28	154	Tested in direction of Grain.
11	,,	0·54	175·1	

Curves for all specimens of 0·03 in. thickness shown in full lines and for 0·018 in. thickness in dotted lines.

rubber tape in the French Regulations (see Appendix B. 2), the stretching test is omitted from the official regulations, not only in this country, but also in Germany and the United States. Various forms of the stretching test are discussed under the head of Testing of Insulation (see page 75), but the author desires to give here a series of results to justify the claim that the stretching test will discriminate between

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good and bad rubber, though not so fully as the hysteresis test will do.

The effect of varying degrees of vulcanisation on the tensile strength and elongation of Para rubber has already been discussed (see Fig. 6), and it remains to be seen what effect the various admixtures used in compounding the rubber have on these two quantities. Heinzerling and Pahl,* in a laborious and exhaustive examination, have dealt in great detail with the effect of various admixtures on the chemical and physical properties of rubber.

Table XII. gives extracts from the results they obtained with

TABLE XII. (HEINZERLING AND PAHL).

Effect of Various Admixtures on the Distensibility of Vulcanised Rubber (10 per cent. Sulphur).

Reference Number.	Para per Cent.	Admixtures. Quantity per Cent.	Admixtures. Nature.	Distensibility per sq. mm. on 100 mm. Length.
I.	90	0	—	1,100
VII.	80	5 5	Zinc oxide Chalk	760
VIII.	50	20 20	Zinc oxide Chalk	710
XVI.	30	60	Brown substitute ...	360
XVII.	50	40	White substitute ...	600
XVIII.	30	60	„ „ ...	455
XXXI.	60	30	Ground rubber waste	650
XXXII.	30	60	„ „ „	600

specially prepared samples containing 10 per cent. of sulphur and vulcanised for one hour at a temperature of from 135° to 138° C.

The same investigators give further a number of analyses of various commercial rubber articles with their physical properties. An extract from these is given in Table XIII.

DIMENSIONS OF TEST PIECES.

Rubber when under tension flows freely, and in order to ascertain what influence the dimensions of the specimen employed had on the

* *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1891–1892.

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calculated breaking stress per square inch the following experiments were undertaken :—

(1) Variation of length; width and thickness constant.
(2) Variation of width; length and thickness constant.
(3) Variation of thickness; length and width constant.

The results are shown graphically in Figs. 17 and 18.

A consideration of Fig. 17, which gives the results for "cut" strip shows very clearly the difference in tensile strength and elongation in

TABLE XIII. (HEINZERLING AND PAHL).

Effect of Admixtures on the Physical Properties of Various Commercial Rubber Articles.

Reference Number.	Indiarubber per Cent.	Sulphur per Cent.	Admixtures.		Spec. Grav.		Distensibility per sq. mm. on 100-mm. Length.
			Quantity per Cent.	Nature.	After Manufacture.	After 2½ Years.	
1	91	9	0	—	0·990	0·999	675
2	82	8	10	Chalk	1·100	1·111	600
3	43	5	7 45	Brown substitute Zinc oxide	1·400	1·490	580
4	47	7	27 16	Chalk Zinc oxide	1·400	1·500	160
5	66	0	16 9 9	Golden sulphide Chalk Zinc oxide	1·200	1·304	235
10	36	6	4 27 27	Brown substitute Chalk Zinc oxide	1·550	1·720	550

this material when tested across the grain and with the grain. When tested across the grain, the specimens begin to fail by opening transversely at the edges, while with the grain they thin out first at the centre, where a slit develops.

In general within the limits given the disturbing effect of the dimensions is not very large except in the case of width; very wide strip should be avoided owing to the difficulty in clamping it so that the stress is evenly distributed.

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The experiments shown in Table XIV. were carried out by the author and Mr. R. K. Keer on pure rubber "spread" tape to ascertain its rate of recovery after a given extension for definite times.

A consideration of this table shows that a reduction in the amount of sub-permanent set goes on throughout the twenty-four hours after testing; indeed, it will continue as a diminishing quantity for several days. The amount of "permanent" set increases with the time the

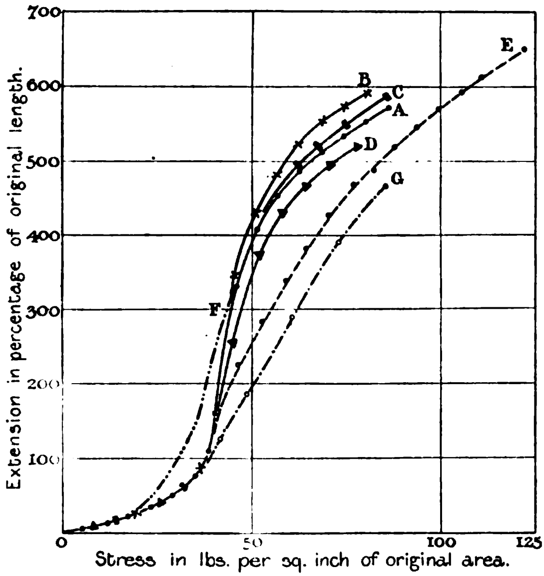

FIG. 18.—Effect of Dimensions of Test Piece. "*Spread*" Rubber Strip.

Effect of Length.

		In.		In.
A, B, C.	Width	0·71	Thickness	0·024
D.	„	0·67	„	0·022

		In.		Lbs. per sq. in.
A.	Length	0·5	Broke at	92·6
B.	„	1·0	„ „	86·8
C.	„	2·0	„ „	92·6
D.	„	6·0	„ „	85·0

Effect of Width and Thickness.

Constant Length, 2 Ins.

		In.		In.		Lbs. per sq. in.
E.	Width	0·32	Thickness	0·011	Broke at	130
F.	„	0·51	„	0·015	„ „	62·5
G.	„	0·77	„	0·011	„ „	98·4

specimen is under tension and also depends upon the rate at which the stretching takes place. A reference to the stretching tests now in use (Appendix B) shows that these facts have not been considered in drawing up these tests. There does not seem to be any gain in measuring the "permanent set" a number of hours after release.

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Table XIV.

Recovery of Rubber after Stretching.

Pure spread tape ; initial length 2 ins., width ¾ in., thickness 25 mils.

Experiment Number.	Percentage Extension on Original Length.	Time of Stretching.	Time during which Specimen was left Stretched.	Length in Inches at Release.	Length in Inches at the following Periods after Release:—			
					1 min.	1 hour.	6 hours.	24 hours.
1	100	3 secs.	Released at once	2·20	2·07	2·02	2·01	2·00
2	200	„	„ „	2·30	2·16	2·09	2·06	2·05
3	100	„	1 hour	2·60	2·43	2·41	2·24	2·17
4	200	„	„	4·10	3·79	3·03	2·65	2·55
5	100	„	24 hours	3·70	3·58	3·12	2·81	2·57
6	200	„	„	4·87	4·65	4·08	3·65	3·29
7	100	½ in. every 2 mins.	Released when stretched to limit 8 mins.	2·56	2·36	2·11	2·06	2·03
8	200	„ „	„ „ „ 16 mins.	3·38	2·98	2·45	2·29	2·22
9	100	„ „	8 mins. for stretching + 1 hour ...	3·10	2·90	2·41	2·22	2·13
10	200	„ „	16 „ „ „	Broke	after str	etching	for ¾ h	our.
10	200	„ „	16 „ „ „	4·12	3·86	3·06	2·71	2·51
11	100	„ „	8 „ „ + 6 hours ...	3·31	3·15	2·70	2·45*	2·26
12	200	„ „	16 „ „ „ ...	4·50	4·25	3·54	3·19†	2 68

* In this case time was only 5½ hours.

† In this case time was only 5 hours.

IX. Tests on Completed Flexibles.

In the spring of last year, at the instance and for the information of the Wiring Rules Committee of this Institution, the author carried out in the laboratories of the Municipal School of Technology, Manchester, the following series of tests on complete flexibles:—

(1) Tensile strength.
(2) Bending on a counterweight fitting.
(3) Dielectric strength I.E.E. Rules.

The following samples of twin flexibles were submitted for tests:—

Test Piece Reference Number.	Size.	Description of Insulation.	Firm.
1	35/40	Thin V.I.R.	A
2	35/40	I.E.E.	A
3	35/38	V.I.R.	A
4	23/36	C.M.A.	A
5	23/36	C.M.A., Class II.	B
6	35/40	Double pure rubber	B
7	35/40	Single pure rubber	B
8	35/40	Double pure rubber	C
9	35/40	V.I.R.	C
10	35/40	C.M.A., single pure rubber ...	C
*11	35/38	V.I.R.	B
*12	35/38	V.I.R.	D

I.E.E. = to specification of the Institution of Electrical Engineers.
C.M.A = to specification of the Cable Makers' Association.
V.I.R. = vulcanised indiarubber.

(1) *Tests for Tensile Strength.*—These tests were made on a horizontal Buckton machine reading down to 10 lbs., two specimens of each sample being tested. The results are given in detail in Table XV. The test piece was short-circuited at one end and about 2 ins. at each end were tightly lapped with several layers of black tape. The taped ends were held in the jaws of the machine with an initial length of 1 ft. of flexible between them. This method of grip was found to be quite satisfactory. A small incandescent lamp was connected in series with the flexible under test to some cells with the object of showing by the extinction of the lamp when the copper conductor broke.

A consideration of Table XV. shows that the breaking force varies a good deal with different specimens of the same sectional area. This

* Samples five years old in use in the School of Technology, Manchester.

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is probably due to the way in which the twin conductors are twisted together, for if one is slightly shorter than the other it will bear a larger proportion of the load. The tests show, broadly speaking, that flexibles of the sizes submitted will break with about 100 lbs. when new. This is very much in excess of any load they are likely to be called upon to bear. As might be anticipated, the copper in nearly

TABLE XV.

Mechanical Strength of Flexibles.

Test Piece Reference Number.	Size.	Breaking Load on Flexible in Lbs.	Bending Test on Counter-weight Fitting. Number of Times up and down over 1½-inch Pulley. (Up and down = 1.)
1 a / b	35/40	71 / 93	58,850
2 a / b	35/40	127 / 138	181,470
3 a / b	35/38	104 / 104	54,370
4 a / b	23/36	104 / 82	70,181
5 a / b	23/36	60 / 82	130,699
6 a / b	35/40	71 / 93	105,262
7 a / b	35/40	123 / 146	200,230
8 a / b	35/40	82 / 160	117,952
9 a / b	35/40	104 / —	17,736
10 a / b	35/40	93 / 194	9,560
11 a / b	35/38	104 / —	265,294
12 a / b	35/38	116 / 105	340,000
Special Gymp flexible	—	—	1,500,000 (still unbroken)

every case breaks before the rubber. It breaks very cleanly right across all the strands with a considerable reduction of area, hardening, and loss of flexibility. In the case of C.M.A. flexible supplied by two different firms the rubber broke first. Where the copper breaks first and the load is removed, the rubber will contract and bring the broken ends of the wires into contact, and so give rise to arcing. This is not very likely to occur in practice, but the author finds as a result of a series of tests, referred to on the next page, on repeated bending through

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a right angle at a lamp-holder, that the copper in this case also breaks first, and that the broken ends are almost invariably pulled together again by the contraction of the rubber when the weight of the fitting is taken off the cord. The average percentage elongation before rupture on a 12-in. length was 25 per cent. Test pieces Nos. 11 and 12 were

Table XVI.

Tensile Strength of Flexibles.—Second Series.

SINGLE FLEXIBLES.

Reference Number.	Size.	Description.	Breaking Load in Lbs.
41	61/0·006	V.I.R. Glacé	71
43	61/0·006	V.I.R. Silk	77
42	35/0·006	V.I.R. Glacé	44
44	35/0·006	V.I.R. Silk	49
46	35/40	Special thin V.I.R. Glacé	39
48	35/40	Ditto Silk	29
47	70/40	Ditto, ditto	60
45	70/40	Ditto Glacé	55
49	23/36	C.M.A. Silk	45
50	23/36	C.M.A. Glacé	42
51	40/36	C.M.A. Silk	74
52	40/36	C.M.A. Glacé	70

TENSILE STRENGTH OF BARE CONDUCTORS.

Size.	Description.	Breaking Load in Lbs.	Firm.
40/36	Tinned	68	B
40/36	,,	69	A
23/36	,,	38	B
23/36	,,	38	A
35/40	Pure copper	23	B
70/40	,, ,,	48	B
100/40	,, ,,	72	A
35/0·006	,, ,,	38	B
61/0·006	,, ,,	67	B

cut from flexible that had been in use in the School of Technology, Manchester, for the past five years. The tests show that practically no deterioration as regards tensile strength has taken place. There was, however, a notable decrease in the percentage elongation (12 per cent.) due doubtless to the hardening of the insulation, and to the slack in the twisting being taken up by the weight of the fitting. It may

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possibly also be due in part to the hardening to which copper is subject if left for a long time under even moderate loads. The author felt that a dead load test would be preferable, and Tables XVI. and XVII. embody the results of a number of tests of flexibles of different grades carried out with a Salter spring balance. The flexibles were attached to lamp-holders at either end, and were knotted at the back of the cord grips, which were screwed up tightly. This form of grip proved quite satisfactory, the tension being put on by means of a screw and wheel nut.

(2) *Bending Test on a Counterweight Fitting.*—One of the severest conditions that a flexible conductor has to meet in house installation work is its use on an ordinary counterweight fitting. An apparatus was arranged to simulate as nearly as possible the bending met with under working conditions. The flexible was drawn down by an attachment to a small motor and drawn up again by the counterweight once in each revolution of the motor. The motor, which was $\frac{1}{12}$ H.P., was fed through the flexible under test and the revolutions counted until a breakage occurred in the conductor, when the motor stopped. The following are the particulars of the apparatus:—

Diameter of porcelain pulley	$1\frac{1}{2}$ ins.
Length of pull	6 ins.
Weight of counterweight	$1\frac{3}{4}$ lbs.

The results are incorporated in Table XV. (see page 70), and are certainly surprising as the extent of the endurance of flexibles under such conditions. Since the conclusion of these tests the author received from Mr. Mervyn O'Gorman a specimen of special "Gymp" flexible, the structure of which has already been referred to under the head of "Conductors" (see page 43). After running over 1,600,000 times up and down over the counterweight pulley the condition of this flexible was, as far as one could see, quite unaffected, and the attempt to break it was abandoned. The author understands that this material costs about £60 per mile, and the resistance is very high, amounting to 1·70 ohms per yard of double conductor on the specimen tested. In connection with lifts and hoists, when the ordinary flexible gives a good deal of trouble the use of "Gymp" flexible would appear to be advantageous.

Bending Tests through a Right Angle.—Flexibles in mills and factories are subjected to frequent brushing to rid them of adherent dirt, and this entails bending at the lamp-holder, also counterweight fittings are usually adjusted by grasping the lamp shade with a similar result. In order to ascertain the effect of repeated bending the author tested about sixty varieties of flexible in the following way. Five lamp-holders were mounted in a line on a wood batten with a short length of flexible depending from each, to which a 3-lb. weight was attached. The ends of the flexibles in the lamp-holder were connected in series, and a small motor ($\frac{1}{12}$ H.P.) was fed through this circuit. The motor was arranged to rock the lamp-holders through a right angle about the ends of the

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cord grips as centre once each revolution. When a conductor broke the motor stopped, and the reading was taken on the revolution counter attached to the motor. The flexibles were carefully inserted and treated as far as possible in the same way, and a selection from the results are given in Table XVII.

TABLE XVII.

Bending Test through a Right Angle at a Lamp-holder.

Test Piece Reference Number.	Size of Conductors.	Average Breaking Load, in Lbs.	Number of Right Angle Bends under Tension of 3 Lbs.	Description of Insulation and Finish.
101	61/·006=1/18	135	1,680	V.I.R. Glacé twin twisted
128	61/·006	—	86,810	V.I.R. Workshop
132	61/·006	—	8,250	V.I.R. Glacé circular twin
102	35/·006=1/20	93	780	V.I.R. Glacé twin twisted
112	35/·006	101	3,680	V.I.R. Silk twin twisted
131	35/·006	—	7,050	V.I.R. circular twin
104	35/40	68	9,880	Special thin V.I.R. silk twin twisted
126	35/40	127	91,860	Special thin workshop
137	35/40	97	2,470	Special thin silk circular twin
108	23/36	86	2,500	C.M.A. silk twin twisted
118	23/36	—	870	C.M.A. Glacé
124	23/36	—	4,910	C.M.A. Glacé
107	40/36	134	5,010	C.M.A. Glacé
116	40/36	—	6,880	C.M.A. Glacé
130	40/36	—	154,990	C.M.A. Workshop
150	40/36	—	2,490	C.M.A. Silk twin twisted
103	70/40	121	3,600	Special thin V.I.R. silk twin twisted
125	70/40	—	26,140	Special thin V.I.R. workshop
135	70/40	—	1,690	Special thin V.I.R. circular
154	36/38	—	2,310	Twin circular silk, 2,000 megohms
155	36/38	—	2,110	Twin circular Glacé, 200 megohms
156	64/38	—	44,580	Twin twisted silk, 200 megohms
157	64/38	—	3,190	Twin twisted Glacé, 200 megohms

It will be noticed that considerable differences exist in the behaviour of different conductors of the same sectional area and gauge of wire. This may, of course, be due in part to differences of manufacture or material, but the author is inclined to attribute it to the position of the

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flexible where it entered the cord-grip and where the bending took place. The two conductors may have the axis of their cross-sections at right angles to the axis of bending, or parallel to it, or in any positions intermediate to these. In practice any of these positions may be dealt with, and the figures given may therefore be taken as an indication as to what might occur in actual work.

(3) *Dielectric Strength.*—The samples were first subjected to the insulation test as set out in the 1903 edition of the Wiring Rules. The

TABLE XVIIA.

Dielectric Strength of Flexibles.

Test Piece Reference Number.	Thickness of Rubber in Mils.	Breakdown Pressure, in Volts.	Nature of Insulation from Observations.
1	16	8,000	Cotton over conductor V.I.R. only
2	17	21,500	Pure rubber, two layers laid opposite ways
3	27	24,200	V.I.R. separator and pure rubber with longitudinal joints
4	34	23,300	V.I.R. separator and pure rubber. Poor and overcured. No cotton next conductor
5	35	26,000	V.I.R. separator and pure rubber of good quality. No cotton next conductor
6	19	21,000	Pure rubber, two layers
7	8	5,100	Cotton braid, cotton yarn, single layer pure rubber. Cotton next conductor
8	24	25,000	Cotton braid, double layer pure rubber. Cotton next conductor
9	34	22,000	V.I.R. separator and pure rubber
10	—	3,200	Cotton braid, single layer pure rubber. Cotton next conductor
11	24	20,000	V.I.R. and separator. Cotton next conductor. Double braided. Five years old

conditions of this test are well known and need not be referred to here. In the tests, the details of which are embodied in Table XVIIA, the flexibles were suspended from supports 3 ft. apart, and were at their centres about 4 ins. from a pan of boiling water 14 ins. in diameter. All the samples submitted successfully withstood the I.E.E. test, and were afterwards tested with a gradually increasing alternating current voltage until they broke down.

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X. Testing of Insulation.

The insulation of flexibles, while following in general the usual lines adopted for rubber cables, is subject to a rather different set of effects, in that the conductors of opposite polarity are in close contact throughout their length, and that the ratio of the amount of surface exposed to the air by the insulation to its thickness is larger in the case of most flexibles than for cables, and the maximum thickness of insulation to be dealt with is small.

Considering the features which it is desirable that the insulation should possess, and placing them in the order of their relative importance, we have :—

(1) Durability.
(2) High initial insulation resistance.
(3) Dielectric strength.

The first is undoubtedly in the case of flexibles the most difficult to obtain, and also the most difficult to test for; while the second, although very generally considered of small importance, often affords a safer guide to the real character of the insulation than the high-voltage puncture test would do. The puncture test for dielectric strength, while usually specified for flexibles, is very rarely carried out in practice.

Table XVIII. gives the puncture voltage, insulation resistance, and electrostatic capacity of some American cables containing definite relative amounts of rubber in their insulation.

Table XVIII. (Clark).*

Significance of Electrical Tests.

Relative Amount of Rubber.	Breakdown E.M.F., in Volts.	Capacity Microfarads per Mile.	Relative Percentage Deterioration in one Year in Elastic Limit.	Insulation Resistance in Megohms per Mile.
1	17,000	2	66	534
2	19,000	1·2	30	1,185
3	18,000	1·0	20	1,150

The above figures are based on twelve tests of each class. They are quoted, not to show absolute values, but to make clear the point that the cheaper grades of insulation do not retain their elasticity. A consideration of the table shows that neither the puncture test values

* "Comments on Present Underground Cable Practice," Wallace S. Clark, *Proceedings American Institute of Electrical Engineers*, vol. 25, 1906, p. 207.

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nor the initial insulation resistance afford accurate indications of the durability of the rubber.

In order that the tests specified for an insulating material may have any real practical value it is essential that they should be simple in character, and easy to carry out. Viewed from this standpoint, any elaborate chemical analysis is out of the question, except in connection with large contracts; and we have to fall back upon the simpler chemical tests, such as the amount of acetone extract and the amount of ash, and the mechanical tests for tensile strength, and elongation, the physical test as to the behaviour in dry and moist heat, and the electrical tests as to dielectric strength and insulation resistance. We have by means of these tests to discriminate between insulation in which a certain minimum quantity of fine Para, Ceylon, or other good rubber has been employed and that into which recovered rubber and rubber substitutes and mineral matter too largely enter.

Pure fine Para rubber contains about 1½ per cent. of matter soluble in acetone, but during the process of vulcanisation this increases to from 3 per cent. to 4·5 per cent. Oxidised oils and rubber substitutes are soluble in acetone, so that the percentage of acetone extract above that native to good vulcanised rubber is a guide to the purity of the rubber.

In order to recognise the relation of the resinous extract obtained to the amount of indiarubber present, the percentage figures for these two constituents should always be calculated separately, so as to show the absolute percentage of resin contained in the indiarubber of the sample alone, and not in the whole contents of the compound.

Table XIX. shows the increase in resinous matter in a few typical varieties of rubber when vulcanised with 10 per cent. of sulphur.

TABLE XIX. (C. O. WEBER).*

Increase in Resinous Matter in Various Rubbers on Vulcanisation with 10 per Cent. of Sulphur.

Brand of Rubber.	Resin in Washed Rubber.	Resin in Vulcanised Rubber.
Para Fine	1·2 per cent.	4·04 per cent.
Ceara	2·1 "	5·12 "
Upper Congo	3·7 "	7·60 "
Lagos	4·5 "	7·13 "
Sierra Leone	6·1 "	9·97 "
Borneo	10·3 "	14·44 "

* "The Chemistry of Indiarubber," London, 1902, p. 264.

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The increase in the resinous extract only occurs in rubbers vulcanised by heat; cold vulcanised rubbers invariably show the normal percentages of resin. A consideration of this table considerably discounts the value of the conclusions based on the acetone extract in respect of the rubber contained in an unknown sample. On the other hand, the amount of extract may always be taken as a safe guide as to whether the sample has been manufactured from Para or not.

The following specification has recently been agreed by the American Rubber Covered Wire Engineers Association * :—

"For insulating compound containing not less than 30 per cent. by weight of fine dry Para rubber.

"The vulcanised rubber compound shall contain not more than 6 per cent. by weight of acetone extract. For this determination the acetone extraction shall be carried on for five hours in a Soxhlet extractor as improved by Dr. C. O. Weber.

"The rubber insulation shall be homogeneous in character, shall be placed concentrically about the conductor, and shall have a tensile strength of not less than 800 lbs. per square inch.

"A sample of vulcanised rubber compound not less than 4 ins. in length shall be cut from the wire with a sharp knife held tangent to the copper. Marks shall be placed on the sample 2 ins. apart. The sample shall then be stretched until the marks are 6 ins. apart and then immediately released; one minute after such release the marks shall not be over 2⅜ ins. apart. The sample shall then be stretched until the marks are 9 ins. apart before breaking. For the purpose of these tests care must be taken in cutting to obtain a proper sample, and the manufacturer shall not be responsible for results obtained from samples improperly cut."

The following elongation test is given by J. Langan † as being intended principally for national code wire, and he considers that even by omitting all conditions as to rubber it would compel results that would be entirely reliable and satisfactory for all conditions of code use.

Elongation Test (*Langan*).—The insulating material of every wire must stand an elongation test of stretching three times its length several times; that is, a piece 2 ins. long must stretch to 6 ins. and promptly return to within 20 per cent. of its original length. It must then stretch four times without break or rupture, and return to 25 per cent. of its original length.

The author has examined a number of specimens of flexibles purporting to be "new and old code wire" and has found them to be poor, hence the necessity for the addition of an elongation test to the tests specified in the national electric code, which are given in Appendix A. *2d*. A detailed examination of "code" wires is given in Appendix D.

* W. S. Clark, *Proceedings American Institute of Electrical Engineers*, vol. 25, No. 4, 1906, p. 203.

† J. Langan, "Rubber-covered Wires." *Ibid.*, p. 189.

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Dry and Moist Heat Tests.—The following tests are generally referred to as "Admiralty tests," but must not be taken as officially representing the Admiralty specifications:—

The "dry heat" test is carried out in an air bath and consists in exposing the samples for one hour to a temperature of 270° F. The "moist heat" test is carried out in a digester at 320° F., the samples having to withstand this temperature for three hours without injury. This test is purposed to disclose the presence of rubber substitutes by their saponification. Pure rubber will not stand these tests, as it melts.

The following elongation test is attributed to the Admiralty, and is certainly the best in common use at the present time: A 14-in. specimen to be clamped for 1 in. at the ends and stretched to double its length—*i.e.* 24 ins.—to remain in this state for twenty-four hours without breaking, and on release after a further twenty-four hours the permanent elongation on the 12-in. length should not exceed 15 per cent.

The relative durability of vulcanised rubber and pure rubber flexibles in mills and other trying situations is a debateable point, and one on which the author hopes the discussion of this paper may throw further light. As things stand at present the Cable Makers' Association only make "C.M.A." flexibles in vulcanised rubber, and if engineers are to pin their faith to this material the author considers that the high-voltage tests should be made after immersion in water. (See Appendices A. *2d*, C. *2d*).

The immersion test could hardly be applied with advantage to pure rubber flexibles on account of the amount of water absorbed by this material.

A consideration of the existing tests detailed above shows a great lack of uniformity and an undoubted want of a reliable "durability" test. The author suggests that a comparison with a standard hysteresis loop, together with a carefully specified stretching test after heating at 150° F. for a given time in air, would give much greater certainty as to the probable durability of the material than any of the tests referred to above. The author hopes to investigate this matter further in the near future, as such a test should be applicable to the thick coatings of large cables as well as to flexibles.

XI. Thickness of Insulation.

A specified thickness of insulation has long been regarded as a desideratum, and where a material of fairly constant composition, such as fine Para rubber, is employed a specification of the thickness to be used may be of value.

Further, it may be desirable for mechanical reasons, or in connection with the oxidation on exposure to the air, to specify certain minimum limits as to thickness with various materials; but the author wishes to urge that, apart from the above, with a highly variable material like vulcanised rubber the specification of the thickness to be employed is not of much value as a guarantee of the subsequent satis-

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factory behaviour of the material. The minimum thicknesses specified in the regulations of various countries are as follows :—

TABLE XX.

Thickness of Insulation for Flexibles.

English.—Pure Rubber, I.E.E. :—

16 mils. up to 125 volts.
20 „ „ 250 „

Vulcanised Rubber, C.M.A. :—

34 mils. smallest conductor.
37 „ largest „

American (see Appendix A. 2*d*).—Vulcanised rubber :—

31 mils. minimum.

French (see Appendix B. 2*a* to *d*).—Vulcanised rubber :—

	Diameter of Core. 1 mm.	2 mm.
(*a*) "Medium" insulation	24 mils.	28 mils.
(*b*) "High" insulation	32 „	36 „
(*c*) "Very high" insulation	40 „	40 „

For pendants the thickness may be reduced to 16 and 24 mils. for classes *a* and *b* respectively if braided with waxed silk.

German (see Appendix C, Table XXIV.).—Vulcanised rubber, smallest conductor: maximum 43 mils., minimum 31 mils.; largest conductor: maximum 55 mils., minimum 39 mils. For counterweight cord, minimum 23 mils.

The vulcanising rubber may be applied to the conductor in two ways. In the first method, which is most commonly adopted in this country, the conductor, after being lapped with pure rubber tape, is laid between two ribands of vulcanising rubber and passed between two grooved steel discs so placed that the grooves form a die of the required diameter. The discs are furnished with cutting edges which shear off the superfluous rubber and cause the freshly cut edges to unite by pressing them together. After vulcanisation the joint is considered to be as strong as the remainder of the material. The author has tested these joints by removing a short length of the conductor and blowing out the tube of insulation thus formed by means of a bicycle pump and valve, and has found that in most cases the joint yields first.

The second method consists in forcing the vulcanising compound by means of a screw worm round the conductor as it passes through a die much in the same way as the lead covering is formed round a cable. In order that the rubber may flow freely the apparatus has to be warm, and the finished insulation must be allowed to cool and

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harden before coiling. This method is largely used on the Continent and in the United States, and although the joint is eliminated, which may be considered an advantage, the conductors will very frequently be found to be considerably decentred.

A cotton wind over the conductors, which is absent in the case of C.M.A. flexible, seems to be desirable, as it prevents the direct contact of the pure rubber and the conductor, which is injurious if the tinning is defective. It also prevents the insulation from sticking to the wires, which it does very tenaciously, making it difficult to get out all the wires for connecting purposes, and it further keeps these wires clean and free from rubber.

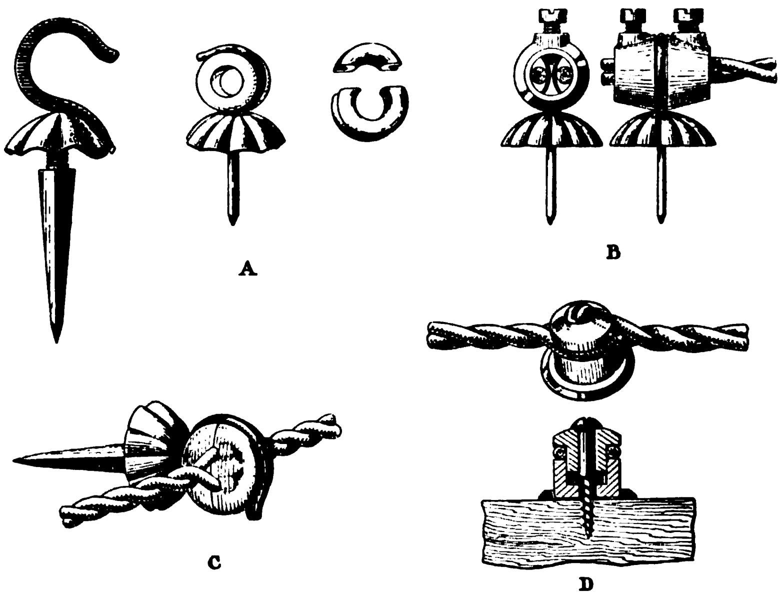

FIG. 19.

XII. FLEXIBLE WIRING SYSTEMS.

These systems, in which flexibles supported on insulators are employed, are used to a considerable extent on the Continent, on account of the cheapness and ease with which they may be installed.

The best known and most widely used of these systems is that of Peschel; it was introduced in Germany in 1893 as being cheaper than wood casing and having a less fire risk.

Originally the so-called ring insulators were employed on this system, the conductors hanging from them in a series of loops, but they are now only occasionally used. They consist of grooved rings of porcelain or coloured glass, either in one piece or split, the latter being used in order to put in extra support to a wire which has

already been run or for heavy cable. These rings are sprung into small spring hooks furnished with either pins, nails, screws, or eyes, as shown at A in Fig. 19.

To strain up the flexibles at intervals special clamp insulators are required. They consist of a short porcelain tube, in which the flexible is held fast by two screws forced down between two fibre strips, causing these to wedge the cord against the tube as B in Fig. 19.

Another form of grip insulator shown at C, Fig. 19, consists of a split insulator with two or three ribbed channels in which the cords

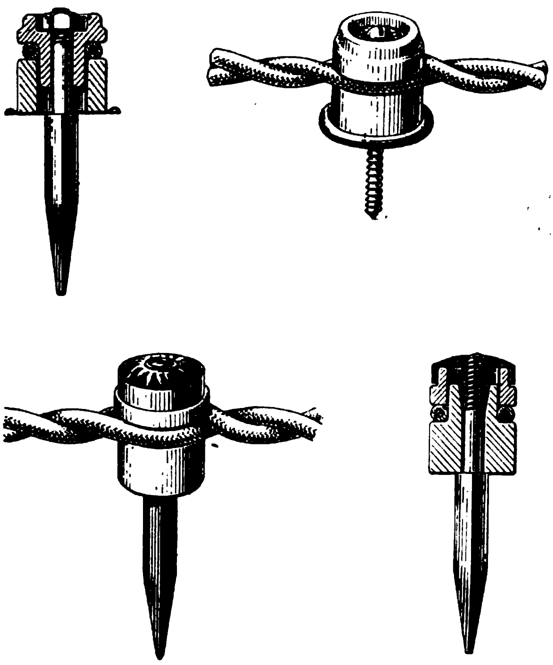

FIG. 20.

are more or less tightly held when the insulator is clamped by the spring hook. The installation of the unsplit rings is inconvenient and unsatisfactory, in that the flexibles are frequently slack, and the wire is damaged when the rooms are cleaned, and further the supporting of the hooks by pins or nails is not very sound except when used on woodwork.

A very much better job is made by employing the type of insulator shown at D in Fig. 19, where on screwing up the fixing screw, one part of the insulator telescopes into the other, gripping the cord between the edges.

In the School of Technology, Manchester, a room has been wired as

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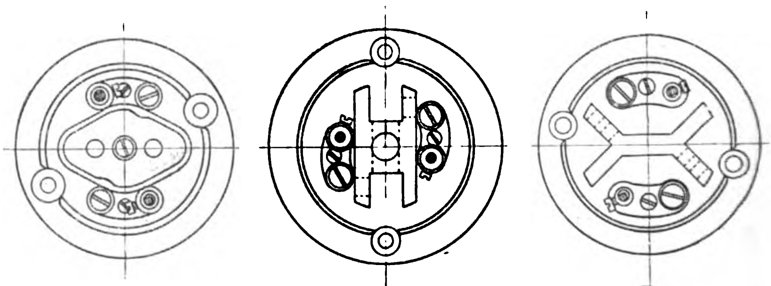
an example of this system, and has given no trouble during the six years it has been installed.

The flexibles, however, when fixed on the Peschel system, are only about half an inch from the walls, and in order to give sufficient space to allow of the walls being distempered without removing the wiring these insulators in Manchester have been mounted on paterases. The flexibles on the Peschel system may, if desired, be taken down and replaced when the redecoration is completed.

An improved form of insulator ("Reformrolle") has been placed on the market by Hartmann and Braun which possesses the considerable advantage that the pressure exerted on the flexible is quite independent of that required for the fixing of the insulator. The various forms are shown in Fig. 20.

The clamp insulators with flexibles are very popular in Germany, one firm alone supplying many millions annually. They are also largely used in France, Italy, Belgium, and Switzerland. There is a



C A B

FIG. 21.

tendency now to run the wires in metal tubes, to secure additional mechanical protection where the lowest prime cost is not an absolute essential.

In Germany cotton-covered flexible costs from 2d. to 4½d. per metre and silk-covered from 4d. to 7d. The prices of the insulators vary from 6d. per 100 for white glazed porcelain to 4s. 10d. for the "Reformrolle," which are intended for well-decorated rooms. It is claimed that flexible wiring can be installed without making a mess or injuring decorations, and in Germany the cost per point exclusive of the lamp-holder, etc., varies from 10s. to 18s.

XIII. ATTACHMENTS FOR FLEXIBLES.

The attachment to the ceiling rose is, generally speaking, satisfactory in the best forms now on the market. With a view to determine the loads which ceiling roses will support without putting any strain upon the terminals, the three types shown in Fig. 21 were selected, and flexibles carefully inserted, the ends being, however, left

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quite free. The load was applied gradually and its value noted when slipping commenced. The average loads for slipping are as follows :—

Type (See Fig. 21).	Load in Lbs.
A	40
B	27
C	45

In some cases it was found that while the insulated covering maintained its position, the conductors were pulled through owing to the

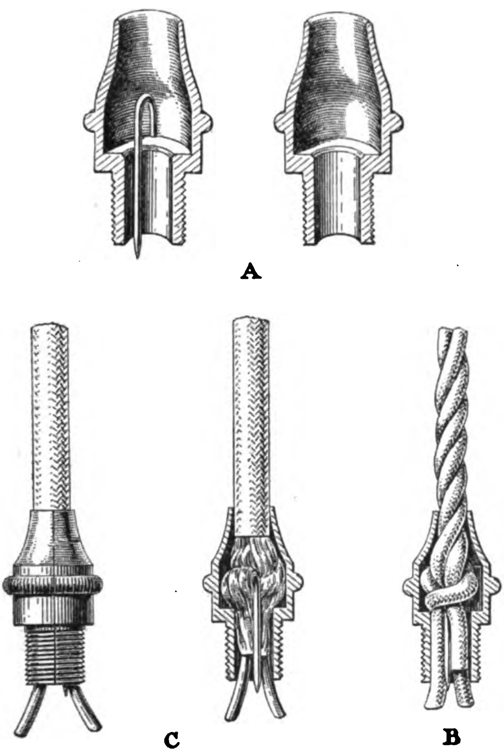

FIG. 22.

extensibility of the covering being considerably greater than that of the conductor. The hole in the cover of the ceiling rose is in many cases too small to admit C.M.A. flexible, which is much to be regretted, as it certainly limits the present use of this excellent material.

With regard to lamp-holders, with twin-twisted flexible the use of the ordinary single-hole cord-grip should be prohibited, and the older

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form with two slots should be reverted to, so that the conductors may be clamped when separated, and not forced tightly together. In general, the cord-grip arrangement is too cramped in design, and a good deal of improvement might be effected without sacrificing the appearance of the fitting.

The cord-grips are commonly made in one piece with a central hole; the wireman has to split the grip down the centre, and enlarge the two half-round channels thus formed to the desired size. The remains of the grip after this operation has been performed are usually of the most slender description.

With circular flexibles the single-hole cord-grip cannot very well be avoided, but in this case the filling that is put in to make up to the circular form helps largely in preventing injury to the insulation of the conductors through their being forced together.

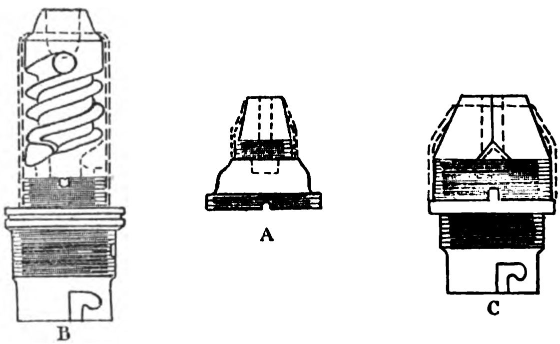

FIG. 23.

The braiding possesses considerable mechanical strength, and this should be taken down into the grip, the ends being whipped or just touched with a trace of Chatterton to prevent fraying.

An interesting series of cord-grip arrangements has been recently put on the Continental market by Messrs. Hartmann and Braun. The various devices are shown in detail in Fig. 22. It must be borne in mind in connection with these fittings that the regulations of the Verband Deutscher Elektrotechniker call for the inclusion of a suspending cord other than the conductors for counterweight flexibles (see Appendix C 2*d*). The nipple which screws into the top of the lamp-holder is made in halves; one half is furnished with a hook, Fig. 22 A, which is passed through a knot in the suspending cord, as at B. With flexibles in which the suspending cord is of stout cotton the hook shown may be placed behind the knot, as at C in Fig. 22.

Some types of cord-grip on the English market are shown in Fig. 23. The average loads at which slipping took place are given in Table XXI.

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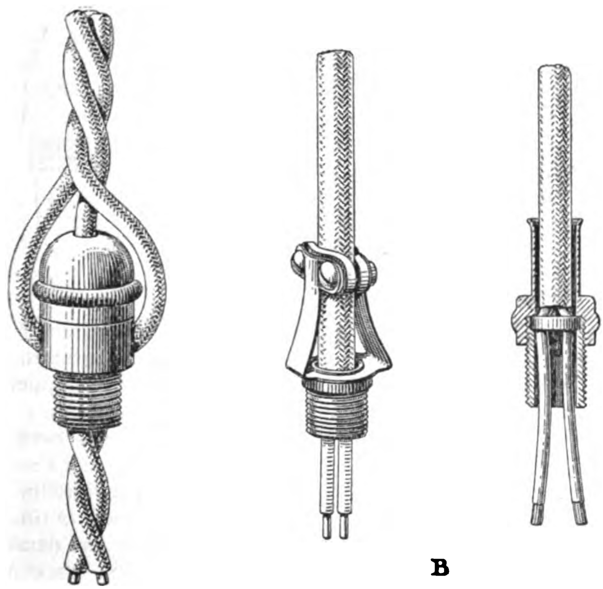
TABLE XXI.

Fig. 23.	English Cord-grips.		Average Load in Lbs. at which Slipping took place.
	Description of Grip.	Type of Flexible.	
A	Boxwood, single-hole...	Twin twisted	20·5
B	Scholes' porcelain spiral	„	28·0
C	Boxwood, single-hole...	„	18·0
	"Thikflex" holder ...	Workshop ...	46·0
D	Boxwood, with two grooves from old lamp-holder ...	Twin twisted	53·0

A further set of attachments by Hartmann and Braun are shown in Fig. 24.



A B

FIG. 24.

In Type A the suspending cord is carried into the screw cap and knotted, the conductors entering the nipple at the sides; in Type B the suspending cord passes through a hole in the centre of a hard fibre disc and is then knotted while the conductors pass through separate holes at the sides of the disc. Both these types possess the advantage that when in use the flexibles cannot be sharply bent at the lamp-holder.

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The weight of fittings commonly supported by flexibles is given in Table XXII.

TABLE XXII.

Weight of Fittings commonly used on 35/40 and 70/40.

	Lbs.	Ozs
Single light pendant, tulip shade, lamp, and holder	0	14
Opal shade 8 ins. × 4 ins. deep	0	15
Enamelled iron shade 10 ins. × 3½ ins. deep	0	12
Three-light ball fitting, tulip shades, lamps, and holders ...	2	11
Three-light spider fitting 12-in. spread shades, etc.	2	14

It is essential that arrangements should be made at the ends of the flexible connecting to plugs, terminals, etc., so that sharp bending may be avoided. This can be done quite simply in a number of ways, but is very usually neglected.

XIV. THE ATTRACTION OF DUST BY FLEXIBLES.

A. A. Campbell Swinton* has shown that the collection of dirt on flexibles is due to electrostatic action, and F. G. Baily† has pointed out that the sign of the potential with regard to the earth is without, or almost without, influence on the result. On both two- and three-wire systems, so long as the switch is on the live side the deposit of dirt will be small, but where it is on the earthed side the deposit will be large, and may extend several inches from the conductor.

With reference to flexible wiring systems, the discoloration of the adjacent walls may be advanced as an objection, but the author would point out that almost any pipe or conduit crossing a horizontal or vertical surface in a room is liable to cause discoloration, which usually takes the form of a light space in the immediate vicinity of the pipe with a dark area beyond it. This is doubtless due to the action of the air-currents when passing the obstruction.

In conclusion, with the scant leisure and the very limited time at the disposal of the author, the compilation of this paper would have been impossible but for the kind co-operation of friends, colleagues, and students. In addition to the acknowledgments already made in the text, the author wishes to express his indebtedness to the following gentlemen :—

Messrs. Lester Taylor, Mervyn O'Gorman, J. Connolly, W. W. Lackie, Llewellyn Foster, A. C. Cormack, H. C. Blackwell, A. F. Guy, and Platt and Bleasdale, for samples and particulars of old flexibles, and their experiences with flexibles.

Messrs. W. C. Popplewell and C. C. Metcalfe, for conduct of the mechanical tests.

Messrs. J. Hubner and F. Sinnatt, for assistance in the experimental work on rubber.

Mr. W. Grant, for detailed reports on a large number of old and new flexibles.

Mr. J. Lustgarten, for high-tension tests.

* *Electrician*, vol. 45, 1900, p. 17. † *Ibid.*, p. 604.

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To the Committee of the School of Technology, Manchester, in the laboratories of which Institution the tests were carried out.

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Messrs. the British Insulated & Helsby Cable Company, Connolly Bros., W. T. Henley's, The London Electric Wire Company, and David Moseley, for a large number of samples, many of which were specially prepared.

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APPENDIX A.

American Regulations (National Electrical Code, 1905).

1. *Installation Rules for Flexible Cord.*

(*a*) Must have an approved insulation and covering.

(*b*) Must not be used where the difference of potential between the two wires is more than 300 volts.

(*c*) Must not be used as a support for clusters.

(*d*) Must not be used except for pendants, wiring of fixtures, portable lamps or motors, and portable heating apparatus.

The practice of making the pendants unnecessarily long and then looping them up with cord adjusters is strongly advised against. It offers a temptation to carry about lamps which are intended to hang freely in the air, and the cord adjusters wear off the insulation very rapidly.

For all portable work, including those pendants which are liable to be moved about sufficiently to come in contact with surrounding objects, flexible wires and cables especially designed to withstand this severe service are on the market, and should be used.

(*e*) Must not be used in show windows.

(*f*) Must be protected by insulated bushings where the cord enters the socket.

(*g*) Must be so suspended that the entire weight of the socket and lamp will be borne by some approved device under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

This is usually accomplished by knots in the cord inside the socket and rosette.

2. *Materials and Construction for Flexible Cord.*

(*a*) Must, except as required for portable heating apparatus, be made of stranded copper conductors, each strand to be not larger than No. 26 (16 mils.) or smaller than No. 30 (10 mils.) B. & S. gauge, and each stranded conductor must be covered by an approved insulation and protected from mechanical injury by a tough braided outer covering.

(*b*) Each stranded conductor must have a carrying capacity equivalent to not less than a No. 18 (40 mils.) B. & S. gauge wire.

(*c*) The covering of each stranded conductor must be made up as follows :—

(1) A tight close wind of fine cotton.
(2) The insulation proper, which shall be waterproof.
(3) An outer cover of silk or cotton.

The wind of copper tends to prevent a broken strand puncturing the insulation and causing a short circuit. It also keeps the rubber from corroding the copper,

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(*d*) The insulation must be solid at least one thirty-second of an inch thick and must show an insulation resistance of fifty megohms per mile throughout two weeks' immersion in water at 70° Fahrenheit, and stand the following tests.

Each foot of the completed covering must show a dielectric strength sufficient to resist throughout five minutes the application of an electro-motive force proportionate to the thickness of insulation in accordance with the following table :—

Breakdown Test on 1 Foot.

Thickness in 64ths inches.	
1	3,000 volts A C.
2	6,000 " "
3	9,000 " "
4	11,000 " "

(*e*) The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out, and where cotton is used it should be impregnated with a flameproof paint, which will not have an injurious effect on the insulation.

(*f*) Flexible cord for use on portable lamps, small motors, or any device which is liable to be carried about must meet all the above requirements as to construction and thickness of insulation, and in addition must have a tough braided cover over the whole. There must also be an extra layer of rubber between the outer cover and the flexible cord, and in moist places the outer cover must be saturated with a moisture-proof compound. In offices, dwellings, or in similar places where the appearance is an essential feature a silk cover may be substituted for the weather-proof braid.

For Portable Heating Apparatus (applies to all smoothing irons, etc., and to any other device requiring more than 250 watts).

(*g*) Must be made up as follows :—

(1) Conductors must be of braided copper, each strand not to be larger than No. 30 (10 mils.) or smaller than No. 36 (5 mils.) B. & S. gauge.

When conductors have a greater carrying capacity than No. 12 (80 mils.) B. & S. gauge they may be braided or stranded with each strand as large as No. 28 (12·2 mils.) B. & S. gauge. If stranded, there must be a tight, close wind of cotton between the conductor and the insulation.

(2) An insulating covering of rubber or other approved material not less than one sixty-fourth inch in thickness.

(3) A braided covering not less than one thirty-second inch thick composed of best quality long fibre asbestos containing not over 5 per cent. of vegetable fibre,

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(4) The several conductors comprising the cord to be enclosed by an outer reinforcing covering not less than one sixty-fourth inch thick, especially designed to resist abrasion and so treated as to prevent the covering from fraying.

APPENDIX B.

FRENCH REGULATIONS (SYNDICAT PROFESSIONEL DES INDUSTRIES ELECTRIQUES, JANUARY, 1906).

1. *Insulation o, Flexible Conductors.*

(*a*) *Medium Insulation.*—This should consist of a layer of cotton and a layer of natural rubber or a layer of vulcanised rubber. Mechanical protection to consist of a layer of silk or glazed braid.

(*b*) *High Insulation.*—This should comprise two layers of natural rubber or two layers of vulcanised rubber. Mechanical protection is to be secured by silk braid or glazed braid.

(*c*) *Flexible Conductors for Pendants.*—Flexibles employed for wiring pendants should be insulated by one or two layers of rubber protected by silk braiding and a plaiting treated with paraffin. This applies to installations up to 110 volts, and the insulation resistance should be 600 megohms per kilometer ($\frac{5}{8}$ mile) after twenty-four hours' immersion in water at 15°C. For 200-volt circuit the insulation should comprise two vulcanised rubber layers, a silk braiding, and a paraffin wrapper giving an insulation resistance of 600 megohms per kilometer. These specifications are given merely as an indication of the practice to be adopted, and there is no obligation to comply with them where the conditions do not admit of doing so.

(*d*) *Nature of Insulation.*—At the time of fixing the insulation of conductors should satisfy the specification; the insulating material should not crack, and conductors covered by an insulating material containing sulphur should be tinned.

Rubber used for insulation may be classed:—

(1) Para rubber tape made of pure Para rubber.
(2) Natural rubber made of indiarubber vulcanised after application.
(3) Vulcanised rubber used as a sheath and vulcanised during the process of manufacturing the wire. If there are several layers, these should be perfectly adherent to one another.

(*e*) *Conductors* for flexible wires or cables should be stranded, each strand being not more than 0·25 mm. (10 mils.) diameter.

(*f*) *Conditions of Installation.*—Conductors having only a "*medium*" insulation can only be employed where the pressure is below 150 volts. When the pressure is 150–250 volts between the conductors or 155–500 in relation to earth, the insulation resistance should not be less than 600 megohms, and when the pressure between the con-

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ductors is between 250 and 500 volts the insulation resistance should be 1,200 megohms at least. The use of metallic ligatures for multiple conductors is forbidden.

For joining flexible wires to one another and to conductors it is recommended to employ rosettes with screwed contacts.

Flexible conductor branchings must be made from the main circuit by means of a contact plug or some similar apparatus.

Regulations other than the above adopted by the Associations françaises de Proprietaires d'Appareils à vapeur ayant un service électrique, the Association des Industriels du Nord, and the Association Normande pour prevenir les Accidents. These rules were drawn up in 1900 and revised in 1903–1904, and are chiefly employed in the North and East of France.

2. *Insulation.*

(1) Para rubber tape made of pure Para rubber and vulcanised without excess of sulphur. At 15° C. (59° F.) and within thirty seconds it ought to be capable of being stretched to six times its length, ten times in succession, without cracking or breaking.

(*a*) "*Medium*" *Insulation.*—This should comprise either (*a*) two layers of Para rubber with necessary braided covering, or (*b*) two layers of "natural" rubber with necessary braiding, or (*c*) one layer of vulcanised rubber, without being watertight. In specifications *a* and *b*, the minimum weight in grammes of rubber per metre of single wire is the same as the diameter of the core in millimetres. In specification *c*, the thickness of the rubber layer should be at least $(0{\cdot}5 + 0{\cdot}1\,d)$ mm. (d being the diameter of the core in mm.). Mechanical protection is to consist of a layer of silk or glazed cotton.

(*b*) "*High*" *Insulation* (300 megohms).—This should comprise two layers of rubber, of which one at least should be vulcanised and completely waterproof, the minimum thickness of which should be $(0{\cdot}7 + 0{\cdot}1\,d)$ mm.

(*c*) "*Very High*" *Insulation* (600 megohms).—This should comprise two layers of vulcanised rubber, completely waterproof, of the following minimum thickness $(0{\cdot}9 + 10{\cdot}0\,d)$ mm.

(*d*) *Flexible Wires for Pendants.*—Flexibles for this purpose corresponding to specifications *a* and *b*, the minimum insulation thickness may be reduced one-third, provided the external protecting layer is of braided silk treated with wax.

Multiple flexible conductors must not be employed in dwellings except in perfectly dry places where explosive mixtures are neither generated nor accumulated, and they should be at least 3 mm. (0·12 in.) from walls and ceilings.

Multiple conductors should be avoided as far as possible for connections with commutators and circuit breakers. In places where there is inflammable dust or nap which becomes attracted to the wires this method will not be allowed.

When there is risk of movable flexible wires getting soaked with

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water (as in dye-works, breweries, etc.), they should be inserted in a rubber tube hermetically sealed at its two extremities.

APPENDIX C.

German Regulations (Issued by the Verband Deutscher Elektrotechniker, June, 1901; amended June, 1904 and 1905).

1. Flexibles may be employed with two classes of insulation, viz.: (i) rubber put on spirally in the form of tape, (ii) rubber in the form of a continuous sheath. Taped rubber flexibles may only be used in dry living rooms for pressures up to 125 volts. They may not be used under dress material or for portable fittings, and may not be installed in cellars, under floors, in bedrooms, or halls. The vulcanised rubber may, however, be used up to 1,000 volts for fixed apparatus and up to 500 volts for portable purposes.

Standard Regulations for Taped and Vulcanised Rubber Flexibles.

2. (*a*) *Taped Rubber Flexibles.*—This insulation may be applied to conductors of from 1 to 4 sq. mm. (0·0015 to 0·0062 sq. in.) in cross-sectional area.

The conductors to consist of stranded tinned copper wires of not more than 0·3 mm. (12 mils.) diameter. The conductor is to be spun over with cotton and lapped with unadulterated pure Para strip, which is to be unvulcanised. The overlap of the tapes is to be at least 2 mm. (0·08 in.). The weight of the rubber covering for 100 metres (109·3 yds.) length of single untwisted conductor is not to be less than the following:—

Table XXIII.

Weight of Insulation on Taped Rubber Flexibles (V.D.E.).

Conductor Section.		Weight of Rubber Covering.	
Sq. mm.	Sq. in.	Grammes per 100 Metres.	Lbs. per 100 Yds.
1·0	0·00155	130	0·262
1·5	0·00232	155	0·313
2·5	0·00388	190	0·384
4·0	0·00620	230	0·464

Note.—For the purpose of testing for the above the mean of five weighings of one-metre sample lengths is to be taken. Tolerance for dimensions and weight, 5 per cent.

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Over the rubber tape each single conductor must have a cotton covering, and over this a braiding of insulating material such as silk or Glacé cotton, which must be non-inflammable.

These conductors must, in a dry condition, be capable of satisfactorily withstanding a test pressure of 500 volts alternating for half an hour.

(*b*) *Vulcanised Rubber Flexibles.*—These are permissible in sections of 0·75 to 6 sq. mm. (0·0011 — 0·0093 sq. in.).

The conductors to consist of stranded tinned copper wire of not more than 0·3 mm. (11·7 mils.) diameter.

The conductors are then to be spun over with cotton and enclosed in a water-tight sheath of vulcanised rubber. The quality of the rubber sheath must be such that it will after twenty-four hours' immersion in water successfully withstand half an hour's application of 2,000 volts alternating between the conductor and the water. The temperature of the water to be not more than 25° C.

The thickness of the rubber covering to be as follows :—

TABLE XXIV.

Thickness of Rubber Covering for Vulcanised Flexibles (V.D.E.).

Cross-sectional Area of Conductor.		Thickness of Rubber Covering.			
		Maximum.		Minimum.	
Sq. mm.	Sq. in.	mm.	mils.	mm.	mils.
0·75	0·00116	1·1	43	0·8	31
1·0	0·00155	1·1	43	0·8	31
1·5	0·00232	1·1	43	0·8	31
2·5	0·00388	1·4	55	1·0	39
4·0	0·00620	1·4	55	1·0	39
6·0	0·00930	1·4	55	1·0	39

Note.—Tolerance for dimensions, 5 per cent.

Each single conductor must be provided over the rubber with a protective sheath, the character of which will depend upon the nature of the work for which it is intended.

(*c*) *Flexibles for Portable Apparatus.*—Conductors for portable apparatus must, in addition to the above, be provided with a suitable covering common to both conductors.

(*d*) *Flexibles for Counterweight Fittings.*—The conductors must have a cross-sectional area of 0·75 sq. mm. (0·0016 sq. in.), made up of stranded tinned copper wires of not more than 0·3 mm. (12 mils.)

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diameter, covered with cotton and with a vulcanised rubber sheath of 0·6 mm. (24 mils.) wall. The two conductors are to be made up with a suspending string or cord of suitable material, and are to receive a common braiding of cotton, hemp, silk, or similar material. The suspending cord can be double and on both sides of the conductors: if it is metallic it must be itself covered with cotton or braided. In connecting up the leads should be left longer than the suspending cord. The completed flexibles must be so pliable that single conductors can be worked over pulleys of 25 mm. (1 in.) diameter and twin conductors over pulleys of 35 mm. (1·38 in.) diameter without injury. These flexibles in a dry condition must be able to withstand an alternating pressure of 1,000 volts.

APPENDIX D.

Detailed Examination of Samples of Vulcanised Flexible now on the Market.

1. 35/40 *Twin-twisted, Marked 3d. per Yard.*

Outside covering, silk, fine.

Dielectric thickness, 0·41 mm., 16 mils.

Dielectric is vulcanised rubber alone. Joints good. Soft, but has very little elasticity.

Cotton over conductors, which are blackened a good deal.

Will not stretch to twice original length.

12 ins. stretched broke at $15\frac{15}{16}$ ins., $17\frac{1}{4}$ ins., $18\frac{1}{8}$ ins.

It might have stretched a little more than this; it was very difficult to strip off.

Percentage of ash, 60·5.

2. 35/40 *Twin-twisted, Marked 2d. per Yard.*

Outside covering, cotton, strong.

Dielectric thickness, 0·41 mm., 16 mils.

Dielectric is vulcanised rubber alone. Soft, but has very little elasticity.

Cotton over conductors, which are blackened.

Percentage of ash, 60·8.

12 ins. stretched broke at 19 ins., $18\frac{3}{8}$ ins., $16\frac{7}{8}$ ins.

Difficult to strip off.

3. 35/38 *Twin-twisted, Marked 1d. per Yard.*

Outside covering, silk.

Inside covering, unwoven cotton lapped round.

Dielectric thickness, 0·65 mm., 26 mils.

Dielectric is pure and vulcanised rubber. One of the longitudinal joints is split. The conductor is badly decentralised. Cotton-covered wires blackened.

Elongation on 12 ins., $1\frac{3}{8}$ ins.

12 ins. stretched broke at $47\frac{1}{4}$ ins., $52\frac{1}{2}$ ins.

Percentage of ash, 57·7.

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4.* *No. and Gauge of Strands*, 35/40.

Braid, maroon cotton, well woven.
Dielectric thickness, 31 mils.
Dielectric thickness should be 30 mils.
Pure rubber, none.
Rubber, ZnO, etc., good even layer } Soft and elastic.
Vulcanised rubber, thin layer }
Elongation on test of 12 ins., $\frac{3}{8}$ in.
12 ins. stretched broke at 4 ft. 5 ins.
Percentage of ash, 37·1.

5. *No. and Gauge of Strands*, 35/40.

Braid, maroon silk, well woven, strong.
Dielectric thickness, 34 mils.
Dielectric thickness should be 30 mils.
Pure rubber, thin clean layer }
Rubber, ZnO, etc., good clean layer } Moderately soft and elastic.
Vulcanised rubber, thin layer }
Elongation on test of 15 ins., broke on test after $\frac{3}{4}$ hour.
12 ins. stretched broke at 31 ins.
Percentage of ash, 34·6.

Remarks.—Double layer of silk thread wound round wires. This flex appears to be very good with the exception of the vulcanised rubber, which cracks and comes off in small pieces when stretched.

6. *No. and Gauge of Strands*, 35/40.

Braid, maroon cotton, well woven.
Dielectric thickness, 32·5 mils.
Dielectric thickness should be 33 mils.
Pure rubber, none.
Rubber, ZnO, etc., thin layer } Soft and elastic.
Vulcanised rubber, thin layer }
Elongation on test of 12 ins., $\frac{13}{16}$ in.
12 ins. stretched broke at 45 ins.
Percentage of Ash, 60.

7. *No. and Gauge of Strands*, 70/40.

Braid, maroon silk.
Dielectric thickness, 12 mils.
Dielectric thickness should be 35 mils.
Pure rubber, none.
Rubber, ZnO, etc., none.
Vulcanised rubber, very thin layer. Inelastic.
Elongation on test of 12 ins., will not stand test.
12 ins. stretched broke at 21 ins.
Percentage of ash, 63·4.

Remarks.—Rubbish.

* Nos. 4–8 extracted from a large number of reports kindly furnished by Mr. W. W. Lackie from tests at Glasgow.

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8. *No. and Gauge of Strands,* 35/40.

Braid, red silk.
Dielectric thickness, 31·5 mils. to 35·5 mils.
Dielectric thickness should be 30 mils.
Pure rubber, none.
Rubber, ZnO, etc. } Thin, dirty, a little hard, and not very elastic.
Vulcanised rubber }
Elongation on test, will not stand elongation test.
4 ins. stretched broke at 9¾ ins.
Percentage of ash, 72·8.

Detailed Examination of C.M.A. Flexibles.

Twin-twisted 23/36.

Insulated with Pure Rubber, Separator, and V.I.R.

	Firm A.	Firm B.	Firm C.	Firm D.
Outside covering ...	Silk	Cotton	Silk	Cotton
Minimum dielectric thickness in mm....	0·86	0·9	0·87	0·65
Minimum dielectric thickness in mils....	34	36	35	26
Condition of strands	slightly discoloured	slightly discoloured	slightly discoloured	slightly discoloured
Percentage of ash ...	48·1	48	44·6	42·1
Elongation on 12″ length after stretching to 24″ for 24 hours (3 samples)	⅝″	⅞″	⅜″	½″
12″ length broke at	5′ 3″	5′ 1″	4′ 7″	5′ 4″

Detailed Examination of American "Code" Wire Flexibles.

Note.—The specimens examined were only 3 ins. long.

C_1, *Marked* 18 *Reinforced Cord, New.*

Outside covering, cotton braid, heavily coated with preservative; then coated over twin cotton-covered leads with what looks like vulcanised bitumen.* Cotton braid over each insulated conductor; then vulcanised bitumen and rubber over cotton-covered conductors, which are badly blackened.

Dielectric thickness, 0·8 mm., 31·5 mils.

* Presence of bitumen confirmed by analysis.

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The conductor is, however, badly decentralised, so that the thickness is much less than this in many places.

Percentage of ash, 60·7 for outside layer.

" " " 62·3 for inside layers.

There is a considerable variation in the gauge of the strands.

The outside layer of vulcanised bitumen has evidently been put on in a plastic condition, as it completely fills up the interstices between the insulated conductors.

C_2, *Marked* 18 *Old Code, Reinforced Cord.*

Outside covering, cotton braid, no coating of preservative; then material which looks like vulcanised rubber over cotton-covered insulated conductors. Cotton over insulated conductors; then vulcanised rubber over cotton-covered conductors, which are also badly blackened.

Dielectric thickness, 0·36 mm., 14 mils.

Joints bad. The dielectric yields suddenly and then breaks when stretched.

Percentage of ash, 55·4 for outside layer.

" " " = 71·2 for inside layers.

Gauge of the strands variable.

C_3, *Marked* 18 *Old Code, Cotton-covered Cord.*

Outside covering, cotton braid; then material which looks like vulcanised bitumen *; then cotton over conductors, which are badly blackened.

Dielectric thickness, 0·72 mm., 28·3 mils.

The thickness is uncertain, as the material was badly cut into by the braid.

Percentage of ash, 62·7.

Wires fairly uniform in gauge.

C_4, *Marked* 18 *New Code, Cotton-covered Cord.*

Outside covering, cotton braid; then material which looks like vulcanised rubber, but might also be vulcanised bitumen.

Cotton over conductors, which are somewhat blackened.

Dielectric thickness, 0·8 mm., 31·5 mils.

Percentage of ash, 63·7.

Large variation in the gauge of the strands.

C_5, *Marked* 18 *New Code, Silk-covered Flexible.*

Outside covering, silk braid; then vulcanised bitumen (?); then cotton over conductors, which are very badly blackened.

Dielectric thickness, 1 mm., 39·3 mils.

This is rather uncertain; conductor slightly decentralised.

Percentage of ash, 62·8.

Gauge of strands fairly uniform.

* Presence of bitumen confirmed by analysis.

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C_6, *Marked* 18 *Old Code, Silk Flexible.*

Outside covering, silk.
Dielectric looks like vulcanised rubber.
Dielectric thickness, 0·41 mm., 16 mils.
Thickness is not uniform.
Cotton over conductors, which are badly blackened.
Percentage of ash, 62·2.
Gauge of strands, fairly uniform.

C_7, *Marked* 22 *Silk-covered. Small Insulation.*

Outside covering, silk braid; then soft, inelastic, putty-like material, which cannot be vulcanised rubber, as the conductors are quite clean.
Cotton over conductors.
Dielectric thickness, 0·28 mm., 11 mils.
Percentage of ash, 69.

APPENDIX E.

Detailed Examination of Samples of Old Flexible.

Vulcanised Flexible.

1. 35/38 *Twin-twisted.*

Outside covering, cotton braid (black).
Inside „ „ „ (blue).
Dielectric thickness, 0·53 mm., 21 mils.
Dielectric is vulcanised rubber, which is soft and fairly elastic.

Cotton over conductors, which are extremely brittle, and are blackened.

Not enough to stretch, but would certainly elongate to four or five times original length before breaking.

2. 35/38 *Workshop.*

Outside covering, strong cotton braid.
Inside „ „ „ „
Then the rubber-covered conductors, laid up with unwoven cotton.
Dielectric thickness, 0·74 mm., 29 mils.

Dielectric is vulcanised rubber and rubber separator. Rubber is hard and inelastic. The conductors are tinned but blackened, and covered with unwoven cotton.

Two samples { 12 ins. stretched broke at 19¼ ins.
„ „ „ „ 18⅝ ins.

Percentage of ash, 54·5.

3. 35/38 *Twin-twisted.*

Outside covering, cotton braid.
Inside „ „ „
Then unwoven cotton laid up with rubber-covered conductors.
Dielectric thickness, 0·77 mm., 30 mils.

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Vulcanised rubber alone seems fairly elastic and strong.

Cotton over conductors, which are tinned and slightly blackened.

Elongation on 12 ins. stretched to 24 ins., $1\frac{7}{8}$ ins.

12 ins. stretched broke at $40\frac{1}{2}$ ins.

Percentage of ash, 53.

35/40 *Workshop.*

Heavy jute braid coated with preservative; this braid is badly finished; then unwoven jute laid up with cotton-covered conductors. There is no rubber of any kind. Conductors fairly clean.

5. 35/50 *Workshop.*

Outside covering, cotton braid, strong.

Inside covering, cotton braid, strong.

Then unwoven cotton laid up with conductors. The two braids are well coated with preservatives.

Dielectric thickness, 0·5 mm., 19·7 mils.

Dielectric is vulcanised rubber and rubber separator. Soft and seems moderately elastic. Decentralised in places.

Strands very brittle. Wires blackened.

Percentage of ash, 42.

Elongation on 12 ins., $\frac{7}{8}$ in. 12 ins. stretched broke at $51\frac{1}{2}$ ins.

6. 26/38 *and* 22/38 *Twin-twisted.*

Outside covering, cotton braid.

Dielectric thickness, 0·73 mm., 28 mils.

Dielectric is rubber separator only, which is very brittle, and crumbles away on bending. This is an example of what inferior material can come to.

Cotton over conductors, which are blackened. Note the unequal number of strands in the two sides.

Will not stretch.

Percentage of ash, 47.

7. 35/40 *Twin-twisted.*

Outside covering, cotton braid, fine.

Dielectric thickness, 0·39 mm., 15·3 mils.

Dielectric is rubber separator only, which is soft like putty.

Cotton over conductors, which are black.

Will not stretch.

54·3 per cent. ash.

8. 35/40 *Twin. June,* 1898, *till Oct.,* 1906.

Outside covering, cotton braid.

Dielectric thickness, 0·62 mm., 24·4 mils.

Dielectric is vulcanised rubber.

Soft, and has little elasticity.

There is also an extremely thin layer of pure rubber.

Conductors black.

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Will not stretch to twice original length.
12 ins. broke at 16⅜ ins.
It was very difficult to strip off.
57·5 per cent. ash.

Pure Rubber-taped Flexibles.

9. 39/39 *Twin.* *Dec.* 14*th*, 1883, *till Aug.*, 1905.

Outside covering, cotton braid; then cotton braid on each insulated conductor.

Dielectric thickness, 0·65 mm., 25·5 mils.

Dielectric pure rubber, soft, and has lost its elasticity.

Cotton over conductors.

Conductors clean.

10. 35/40 *Workshop.* 1888 *to date.*

Outside covering, strong cotton braid, well coated with preservative; then unwoven cotton laid up with insulated conductors; then unwoven cotton over rubber.

Dielectric thickness, 0·1 mm., 4 mils.

Dielectric is pure rubber, and has evidently been put on under considerable tension. It has lost its elasticity.

Cotton over conductors, clean.

11. 35/40 *Twin.* 1889 *to date.*

Outside covering, silk braid.

Unwoven cotton laid up with conductors. Unwoven cotton over insulated conductors.

Dielectric thickness, 0·08 mm., 3·1 mils.

Dielectric is pure rubber.

Soft and slightly elastic still.

Cotton over conductors.

Conductors clean.

12. 35/40 *Twin.* 1886 *to date.*

Outside covering, cotton braid.

Inside covering, cotton braid (thicker).

Dielectric thickness, 0·22 mm., 8·7 mils.

Dielectric is pure rubber, hard, strong, but inelastic.

Cotton over conductors.

Conductors clean.

13. 37/39 *Twin.* 1890 *to date.*

Outside covering, cotton braid; then two layers of unwoven cotton.

No rubber.

Wires untinned. Clean.

14. 21/38 *Twin.*

Outside covering, silk braid; then two layers of unwoven cotton.

No rubber. Wires not tinned. Clean.

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Discussion.

Mr. C. P. Sparks: I have read the paper with much interest, but I have found the mass of detail put at our disposal somewhat difficult to digest in the time I have had to consider the subject. On behalf of the Wiring Rules Committee I wish again to tender to Professor Schwartz our special thanks. Last year, when we had the question of revision of the Rules before us, we were met with the want of data with regard to the flexibles then in common use, and he gave us his very hearty co-operation in elucidating certain points. While I am on this point I should like to say that some five years ago, when the Wiring Rules were under revision, we were faced by the fact that there was no test for flexibles, and after consultation with the manufacturers, a test was proposed which was admittedly inadequate, but it was better than having no test at all. It consisted in specifying a pressure test at 1,000 volts. At that time we were dealing with pure rubber flex, and it being impossible, owing to the absorptive power of pure rubber, to specify an immersion test, we specified what was equivalent to a dry test. Further experience during the last few years showed us that this test was not effectual; and in the last edition of the Rules which has just been issued it will be found that the standard has been raised, and that in the place of testing samples, every hank is to be pressure tested to 1,500 volts for a quarter of an hour. In the meantime, the Cable Makers' Association have produced a vulcanised flex, which is being largely used, and in that case we specify a pressure test, after twenty-four hours' immersion in water, of 1,500 volts for a quarter of an hour. Professor Schwartz has drawn attention to the Rules existing in other countries. Referring to his abstracts, it will be seen that the American rule for the vulcanised flex is a minimum thickness of dielectric of 31 mils. In the Institution minimum we have adopted the Cable Makers' standard of 34 mils. The American pressure test is that after two weeks' immersion in water it is to be tested at 6,000 volts. In our case, after twenty-four hours' immersion in water, the pressure test is 1,500 volts. In Germany the minimum insulation of vulcanised flex is 31 mils., with a pressure test of 2,000 volts after twenty-four hours' immersion in water. In France no dielectric thickness is specified, and there is an insulation test only after twenty-four hours' immersion in water. The author has pointed out the relative merits of vulcanised *versus* pure rubber flex. My own opinion is in favour of the pure rubber flex. No doubt the attraction of vulcanised flex is the fact that the pressure test can be made and the insulation test taken when the cable is in water, and more exacting tests can be made that on pure rubber flex. But the durability of pure rubber flex made with high-class material is, through the absence of sulphur and the smaller deterioration at moderate temperatures, very much in its favour. English experience with flexibles has been largely based upon this material, and the vulcanised flexible must be considered as being upon trial. On page 70 tests are Mr. Sparks.

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Mr. Sparks. given of the mechanical strength of flexibles, tests that were carried out to assist the Committee; while on page 74 some pressure tests are given. We were glad to see that the specimens of flex made to the then Institution Rules came out well above the average. For instance, with regard to the breaking mechanical strength, it failed after 18,100 bends, while it stood a test pressure up to 21,500 volts. Under paragraph 44 of the new Wiring Rules, laying down rules for both pure and vulcanised flex, attention is drawn to the desirability of using pure rubber flex with pendants, or in any position where the wires are often bent. The next point I would like to mention is on page 36, where the question of the grouping of flexible conductors is mentioned. The author says, "In mill and factory lighting, moreover, it is impossible for economic reasons to employ only 5-ampere circuits where long aisles are to be lit." I think there is some misunderstanding on that point, because if necessary one can control a 100- or 200-ampere circuit as a whole. At the same time, each individual part, each 5-ampere circuit, can be effectively guarded so far as fusing is concerned. In revising the Rules some five years ago a rule was introduced, which is now paragraph 21 of the new edition, drawing attention to the necessity, in wiring, of limiting the sub-circuit to 5 amperes at 125 volts and 3 amperes at 250 volts. In my opinion that is one of the soundest and most necessary rules that the Institution has ever issued. If it is carefully adhered to the risks that are undoubtedly run with bad flexible, or carelessly handled flexible, are enormously minimised, because a fuse that will carry 5 amperes is well within the limit of safety, as shown by Professor Schwartz's test of smoking or flaming flexibles. It is so well within that limit, and if circuits are reasonably fused the safety of the whole system is assured by subdivision into these sub-circuits.

With regard to the system of wiring, Professor Schwartz mentions the Continental practice. It is only of recent years that any open wiring work has been permitted, either by the Institution or by the Fire Offices in this country. In the Rules which were re-issued some five years ago permission was given in a tentative way for open work to be carried out, and during the last few years this work has grown. Now, under paragraph 46 (*c*) of the new Wiring Rules, more definite instructions are given as to the way in which this work is to be done, and I think with the use of the sub-circuit system there is a very great field for such work, which will widen the use of electricity, and enable it to be used in many cases where the capital cost of wiring the smaller buildings has prevented its use hitherto. On page 82 of the paper mention is made of the price that might be reached per point with open wiring with flexibles. From my experience that point has not only been reached with other systems, but long since passed, namely, from 10s. to 18s. per point, and represents a standard that I am sure the wiring contractor in this part of the world would welcome if he could obtain as a general rule. The cost of work carried out on the open system is going to be far less per point than that indicated.

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Coming to the second part of the paper, I am much interested in the question of rubber and the suggested hysteresis test. My experience of rubber is not of a very scientific kind. For many years I have been principally a user of either fibre or paper cables. Comparing a sample of rubber cable that one gets to-day, I cannot help feeling that we are dealing with an entirely different article to what we were using in the pioneering days of electrical engineering. Whether the raw material has changed, and for this reason it is not possible to make rubber cables to-day as they were made then or not, I do not know; but it appears to me that one cannot buy the same class of cable as that manufactured here in England twenty years ago. Personally, I believe it to be a question of raw material. I hope the rubber makers will come here, and, without giving away the whole of their trade secrets, throw some light on this matter, because there is a very great want of a reliable test for rubber, not only for the protection of the buyer but also of the seller. The manufacturer in this country is supplying a high-class article, but it is difficult for the buyer in many cases to say, "This cable, although it appears to be 10 or 15 per cent. dearer than another sample, is worth the higher sum." At the moment some of us cannot discriminate; it is only a question of price. And I think the cable makers should help us to draft such a specification that, in the hands of practical men, we can select, and therefore pay for, a better article, instead of relying entirely on the cable maker's reputation. Mr. Sparks.

Mr. A. WHALLEY: I have read the paper with very great interest, especially the point dealing with the high temperature in lamp-holders, and in the next place the excellent results recorded in tests of C.M.A. flexibles. If such excellent results are obtained under the present specifications, does not this indicate that there is no great need for further tests, which must be very complicated in character, and could only be carried out by those having prolonged experience in the manufacture and testing of rubber goods? As regards conductors, and the question of the conductivity of stranded compared with single wires, I would suggest that Professor Schwartz ignore altogether the diameter and area, but from the resistance and weight of a unit length, multiplied together, obtain a constant for the stranded conductor; then take out of the stranded conductor a single wire (which would be hardened, due to the stranding), and also take a single unstranded wire and obtain similar constants for them. This would show whether there was any change in the conductivity. The question of gauging the thickness of tinning, dealt with in Table IV., is a very difficult one. Speaking generally, as pointed out by the author, a small error in gauging, such as one part in sixty, means, perhaps, a 3 per cent. error, or a one part in forty error in diameter means a 5 per cent. error in the area. Such errors with small wires can easily be produced by simply holding the micrometer in the hand a few minutes, causing expansion of the micrometer. The thickness of the tin, as a rule, can only be measured chemically. On a small wire usually it is less than on a large wire, having to be drawn through the tinning bath, if of normal tem- Mr. Whalley.

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Mr. Whalley.

perature, at a greater rate to prevent its being melted, and there is thus a tendency for less tin to be placed on it. This is still generally true. In Table IX. tests are recorded to illustrate the effect of corrosion by sulphur of copper conductors, under conditions of long age, and it is put forward as though the whole of the decrease in tenacity was due to the use of vulcanised rubber. I hardly think the table supports this conclusion. It is easy for the hardening effected in the processes of stranding and of insulating conductors to be greater than any change due to the presence of sulphur outside the copper attacking it. For instance, the percentage extension of a single new tinned wire is 25 per cent. under a breaking stress; of pure rubber flexible, presumably without sulphur, it is 19·5 per cent. on the average; for cotton insulated flexible it is 14·5 per cent. (a loss of 10 per cent. compared with the first figure); while with vulcanised rubber it is 10 per cent. But the breaking stress shows a contrary result, the vulcanised rubber flexible being the strongest of the lot, if we eliminate one very bad sample marked E8. The average breaking load in grammes per square millimetre for pure rubber flex is 19,625, for cotton flex 20,000, and for vulcanised flex 20,500. The author expresses a preference for the use of cotton next to the conductor. This has its advantages and disadvantages. The disadvantages, I think, are that it stiffens the conductor pretty considerably, and next that a high insulation resistance cannot well be obtained with cotton on the conductor. When there is cotton on it it is impossible to get rid, even by gassing, of an almost invisible fluff, and very minute tubes of fibre will cut through the joints or overlap of the pure rubber that is applied to the conductor, and these tubes of fibre lower the insulation.

As regards vulcanised indiarubber itself, I think the author has made a slight slip in mentioning that occasionally as much as 50 per cent. of sulphur is made use of. This could only be approached in such a material as ebonite. The injurious effects of oil, and also copper, are mentioned. Untinned brass is almost as injurious as copper itself. Amongst the numerous causes mentioned of the deterioration of rubber under prolonged heat tests, the effect of copper salts is not included, if the tinning is in any way defective. Preference is expressed by the author, and has also been expressed by Mr. Sparks, for the use of pure rubber flexible, the author preferring pure rubber for high temperature. This fact should not be forgotten, that with a temperature somewhat below 200° F. pure rubber becomes tacky, which condition can also be produced by defects in the tinning of the copper. The exact temperature of tackiness will depend upon the kind of raw rubber used. To show the complicated nature of the subject, it is only necessary to say that there are about forty varieties of Para rubber, and the exact temperature of tackiness is dependent on the nature of the rubber and how it is prepared. Then I should like to say with regard to the proposed hysteresis curve, given in Fig. 10, that for every compound used a temperature coefficient would have to be determined well in advance as the result of a long series of experiments,

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Mr. Whalley.

Temperature has an enormous effect upon the results, especially in what the author calls the retractive curve. The mere fact of handling the rubber has an important effect in this direction. I presume that the results given in Fig. 12 are for the pure rubber, separator and jacket in one piece together, and that the percentage extension is taken at 70 per cent. of the breaking stress as in other cases. The figures given at the bottom of this table do not appear to agree with the curves, as similar figures are given for the flexibles produced by firms "C" and "D," but the curves differ at all points. On page 60, in connection with this same table, it is mentioned that "strips" were tested. I presume this does not mean that the insulation was cut from the cable by slitting it with a knife lengthwise. If so, I think most contradictory results would be obtained. It is almost impossible to make that slit with one stroke of the knife, and if this cannot be done jagged points and breaks in the line of cleavage are bound to occur, and these are points of weakness. It is a matter of some difficulty to prepare a sample properly. The insulation should be taken off the conductor as an unbroken tube, great care being taken that the whole of the pure rubber is intact, none being left attached to the copper, otherwise one gets a bad sample which cannot be tested. The interesting point of the curves shown last of all by the author seems to be that with an increase of above 50 per cent. of pure rubber (in the samples tested) no increase is shown either in the tensile strength or in power to resist the prolonged heat of 150° F. The strongest rubber, looking at it from the tensile point of view, was the 48 per cent. mixture, and those that stood the heat the longest were the 40 to 45 per cent. Regarding the acetone test to determine the percentage of resin in rubber, percentages are given, in the paper, which ought not to be exceeded in raw Para rubber and vulcanised rubber; but the amount of moisture in the rubber may easily equal or exceed these figures, so that extreme precautions are required to get rid of this moisture first of all. Merely heating the rubber on heating rolls does not suffice, and figures at least double, and perhaps treble, those mentioned may be obtained by this test. The prominent result of the curves of stretching tests on mixtures containing known percentages of pure rubber seems to be that we have, in the first half of the curves, a lower rate of slope for the lower mixtures, and as the slope increases it indicates a greater percentage of rubber. We get just the same result with the present stretching tests in some Government and other specifications, wherein the percentage of rubber is prescribed as 35, 50, or 60 per cent., and corresponding increases in the stretching test are prescribed also. In the second part of these curves, the retractive portion, the almost horizontal line present in all cases indicates that the tension upon the rubber was changed at a rate greater than it could respond to, since the rubber only began to contract after the tension had been reduced by as much as 30 to 50 per cent. The testing of rubber is evidently an extremely difficult subject, and while of interest to the purchaser, is still more so to the maker, who has to consider the dielectric strength and also the

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Mr. Whalley.

megohms and life at the same time, but it appears almost impossible to devise any simple test which is reliable, and any increase in the complication of tests would probably increase costs without increasing quality.

Mr. Human.

Mr. H. HUMAN: Looking at the matter from the Fire Office point of view, we have in this paper something we have long wanted. The author has been dealing with what we have assumed to be our weakest link, and it is very satisfactory indeed to find that that link is not so weak as we have been in the habit of regarding it. The net result of this very interesting paper is, to my mind, to elevate flex in our estimation. The paper also explains some things which hitherto have been a mystery to me. For instance, when we look into shop windows and see how flex is there used and abused, we wonder how it is we do not get more fires in those places than we actually do. The explanation is really found in this paper. When I have observed a dresser in a shop window playing with live flex in the same way he would play with a blind cord, I have sometimes wondered whether that man has the slightest conception that within that apparently innocent looking cord there is enough energy to knock him head over heels. But, as a matter of fact, we seldom hear of people being injured by shocks when handling live flex; and it seems to me again that the reason for that is to be found in some of the tables in this paper. Looking at Table XV. and Tables XVII. and XVIIA, we find there very extraordinary results. Some of the figures are perfectly astounding. I had no idea that that stuff which we call flex, and which we regard as an enemy of ours, is capable of standing a stress of 26,000 volts. Then again, look at Table XV., and neglecting for the moment those very extraordinary figures at the bottom, if we take the mean of those experiments we get 130,000 double journeys up and down. In endeavouring to arrive at the prospective life of such flex, and taking, let us say, an average of 2 double ups and downs per day for 365 days in the year, which is a very reasonable average, we get a result of something like 170 years as its probable life. But there is something wanting there that even Professor Schwartz is not able to supply, and that is the factor of age. We know very well that rubber, like a great many other things, depreciates with age; and if we could get some factor representing that depreciation and apply it to Table XV., I think we should have to knock off some of those noughts. Then as to the bending effect, although there is considerable variation in Table XVII., the net result is very satisfactory from our point of view, and it certainly puts workshop flex on a high pinnacle. There is, however, something again wanting here that does not seem to me to come into the experiment, and that is the heat due to the lamp. If lamps had been inserted in the holders we should have obtained that effect, but I do not suppose there are many lamps on the market that would stand the thousands of rockings that the holders underwent; but if we had the heat of the lamp on the rubber at that point of bending, it would probably bring down some of these figures. When that form of adjustable pendant

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Mr. Human.

first came out many years ago, we Fire Office men were in doubt as to how to regard it. Somebody suggested that the counterweight would throw an additional strain on the terminals of the lamp, but it didn't! Then it was suggested that the frequent running over such a small pulley wheel would lead to the fracture of the very delicate strands of the cable, and that that would lead to incipient arcing, which is the danger we have to guard against. But it doesn't! I say so upon the evidence of these tables, and that is a great relief to our minds. With regard to the question as to whether the rubber should be pure or of the vulcanised order, I must say that my leaning has been towards vulcanised rubber, because I regard it as having much better mechanical strength; it resists moisture better than pure rubber, and, theoretically, it should stand heat better. Then, again, in pure flex the coating of rubber is very thin, whereas in the vulcanised there is a substantial thickness. But the evidence we have had of late upsets that theory altogether, which is due to that little factor, the heat of the lamp. That heat appears to destroy both the vulcanised and the pure rubber; but the pure rubber has this bit of luck, that the cotton comes to its aid, and when the rubber is melted the cotton takes it up, thus maintaining the insulation. Then, again, my friend, Mr. Lester Taylor, who has probably held more post-mortems on electrical fires than any other man in this country, is strongly of the opinion that where flex is used in connection with pendant lamps, pure rubber is the proper thing. Therefore it seems to me that this Institution is well justified in recommending pure rubber in such cases. Where mechanical strength, however, is supreme, then possibly we should adhere to vulcanised. But rubber is one of those mysterious things which is elastic in more senses than one—that is to say, there are few things admitting of greater adulteration. When one visits rubber works, and has to go into the question of the various things they employ, one gets a very long list. Many of those things are doubtless justifiable as strengthening the product, but there are many that have as much relation to rubber as sand has to sugar—mere fillers. When lately discussing the point with a well-known authority, as to whether it would not be possible to get out some standard test of a mechanical nature, such as a stretching test, he said, "No, it is quite possible to produce an inferior rubber that would answer the test at first, but would absolutely fail to do so in the course of a few months." Well, where are we? The fact is we are in the hands of the cable makers, and our only salvation, so far as I can see, is to put ourselves in the hands of those makers who have some reputation to sustain.

Mr. Wansbrough.

E. C. WANSBROUGH: The general conclusions of the author regarding the advantage of pure rubber over vulcanised have been supported by so many previous speakers, that there is no need for me to discuss them further, but I should just like to say that I entirely agree with them.

The author mentions, in connection with Fig. 4, sundry tests, and amongst other things he shows that the temperature obtained with bare

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Mr. Wansbrough. wire is higher than with covered wire; but a bare wire which is freely exposed to the atmosphere will remain at a lower temperature for a given current than the same wire enclosed in a tube of insulation. Perhaps he will kindly clear this point up in his reply.

On page 75 the author pins his faith to a high initial insulation resistance test as being a very safe guide to the real character of the insulation. He says, "This is generally considered of small importance." Rightly so too, inasmuch as it is perfectly easy to obtain high initial insulation resistance with materials that possess very poor durability. In my opinion the test specified in the I.E.E. Rules, if honestly and fairly carried out, would prove of considerable assistance in eliminating poor and defective material. The variations in behaviour under the author's tests were only to be expected, rubber being a natural organic product, liable to slight variations in composition which affect to a considerable degree its mechanical and electrical properties. Hence the necessity on the part of manufacturers for most careful selection of their raw material and rigorous inspection and testing during construction. This is done by the high-class makers, but the present-day craze for cheapness keeps the sale of high-grade guaranteed flex within very narrow limits.

On page 53 some of the extraordinary things are mentioned which go to make up so-called V.I.R. flexible. To my certain knowledge these dangerous compounds have a most extensive sale, and I am greatly surprised that at this late day, surrounded as we are by such a multiplicity of Wiring Rules, they should be allowed. I am hoping that the new Wiring Rules which have been foreshadowed by the President to-night, with their strong preference for pure rubber, will rid us entirely of these undesirable aliens.

Mr. O'Gorman. Mr. M. O'GORMAN: When Professor Schwartz gave the paper the unpretentious title of "Flexibles," I am bound to say I did not expect that we should have such a valuable study upon the subject of testing rubber. I shall carry away from hearing this paper two lessons, and I hope Professor Schwartz will endorse my view: the first, that vulcanised flexible has been tried and found wanting—an opinion, I am glad to say, that has been also re-echoed round the room to-night; the second, that a mechanical test which will sift good rubber compound from bad is within sight. In my experience vulcanised flexible is to be avoided in almost all cases. This conclusion may not, perhaps, be universally held, but I have been led to it after a course of years and after having begun as an enthusiast in its favour. I could give reasons for that opinion, but I think it is too late to enter into them. The author's experiments, as I understand their logical outcome, practically lead to the same result, although they help to show the safety in use of flexibles generally. The objection to vulcanised flexibles is chiefly limited to this: that it is in no part of its design calculated to support a weight for a long time. The soft copper wires—for they should be soft—are liable to be made brittle by being tinned. The vulcanised rubber which is, as a matter of fact,

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almost invariably under-vulcanised in flexibles, presumably because of the danger of having too much sulphur, which will attack the fine wires, is useless in tension as a weight carrier; and lastly, the braid, which might be gripped in the ceiling rose and in the cord grip of the lamp-holder, is liable to almost indefinite extension because the material under it diminishes in diameter with stretching and so permits the braid to assume a greater length without difficulty. Such a flexible may nevertheless be excellent for portable fittings, provided no cord absorbers or pulleys be used with it. In running up and down over pulleys the rubber, if under-vulcanised, acts as a sort of lubricant between the copper strand and the braid; it becomes deformed and does not seem to recover. This appears almost universal in thickly coated vulcanised flexibles. I have seen expensive C.M.A. flexible replaced with improved results by very much cheaper material, which was certainly not waterproof and was undoubtedly covered with inferior pure rubber of African origin. I have seen this happen in damp places—for instance, in a paper mill, than which there is nothing damper—where plain pure rubber and cotton covered flexible was far better in performance. Part of the result is ascribable to the important effect pointed out by the author of the heat of the lamp-holder on the under-vulcanised rubber. A minor point of great interest which has been brought out by the lecturer's experiments is the existence of the persistent low-current arc between the members of a pair, to which vulcanised rubber flexibles are more prone than pure rubber. Mr. O'Gorman.

Even after all the work done by the author we still have to find a satisfactory test for flexibles. Our test is to maintain 1,500 volts between members of a pair, but we have seen to-night that all sorts of flexibles, good and bad, will stand 6,000, 7,000, 8,000, and 9,000 volts, so that 2,000 volts is the sort of test which may amuse the tester but will not discriminate between good and bad flexibles. It is better than nothing in one respect, namely, that it picks out those little broken strands which poke their way through the rubber and would not be detected because of the absence of the immersion test. In spite of these remarks I am sure we have done rightly in the Wiring Rules Committee in saying that houses may be wired entirely with this untestable material. The author has mentioned that the tensile strength of the core is diminished by temperature, and I take it he leaves it to be implied that this is not a permanent diminution; it simply occurs when the material is hot. My name has been associated, in flattering terms, with the flexible at the end of Table XV., which has had an extraordinarily long life. I was very enthusiastic on the subject, and I think called for it in the first place, but the people to whom the credit is due are undoubtedly the makers, the British Insulated Wire Company. I have tried it very severely in practice for, I think, eighteen months or so in a differential pulley cord absorber, and it stands the test very well; in fact it stands tests which no other flexible has ever stood. It is noteworthy that this

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Mr. O'Gorman.

material is, owing to its very recentness, excluded from use under our new Wiring Rules on the score of lack of conductivity, but that is the sort of thing for a permanent Wiring Rules Committee to deal with. I do not doubt but that it may on special occasions be admitted.

The author asked a question as to why twenty-four hours is used in the stretching rubber test. I was one, I think, of quite the early votaries of the stretching test of rubber, and I am glad to see that his work leads to a more scientific style of stretching test. Although Mr. Human was informed by some person—who, I presume, is antagonistic to the testing of rubber by the buyer—that a stretching test was useless because he could obtain *any* stretching result with a material that would be worthless in three months, I greatly doubt whether this rapid deterioration of such a material would be obtained commercially in conjunction with the good electrical test usually required; but that remains to be seen. I daresay Professor Schwartz will make a study of the relative rates of decay of the good and bad rubbers of which he gives curves, because that will make his tests even more important. He is, I think, in favour of the stretching method, and I believe it to be the only practical way of testing cables at all, except the method of lengthy immersion, which is too slow and expensive. A twenty-four hours continuous stretch of rubber is made to ensure that the temperature of the sample is the same as the temperature of the air, otherwise it is difficult to get at the temperature of the sample. One cannot get inside it, and so care must be taken that the whole of the test lasts for twenty-four hours. The temperature of the room then gives that of the cable. As regards speed of stretching, which I agree is important, we have always used a very slow speed worm-wheel arrangement, and I think the time of stretching is about six seconds; at any rate it is nearly a constant speed and comparative as between various samples. Mr. Sparks referred to a subject on which I wish to strengthen his opinion in every possible way. He stated that the importance and advantage of having a stretching test which really indicates the quality of rubber does not solely advantage the buyer or the consulting engineer. It is of value to the maker, who wants us to distinguish good from bad. It relieves us from the necessity of relying absolutely upon the name of the maker. Moreover it is good for the industry to give a chance to the people who are building up a cable business by making good stuff, even though they have not years of history behind them.

Mr. Connolly.

Mr. J. CONNOLLY (*communicated*): I must in the first place congratulate Professor Schwartz on having made a distinct addition to the information available on this subject, and while it is quite evident to any one interested who has seriously studied his paper that the last word has not yet been said on the question of flexibles or of indiarubber insulation, I am of opinion that he has made an important advance towards solving the problem of distinguishing between good and bad, between what will endure and what will perish.

I would give the first place in importance to the hysteresis curves

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shown in Fig. 12. Tests, similar to those on which these results are based, have been used on a rough scale by manufacturers of vulcanised elastic thread, who place great confidence in estimating the quality of the thread by observing its tractile strength against varying loads. I deduce from his results that the curves for inferior material will be found outside the range of the curves for good material, and will fail, either on the side of extensibility or of breaking load, or of both. I think that similar experiments on the insulation of larger size wires and cables are desirable. I hope they will be carried out soon, and that a good practical and reliable test will be the outcome. Mr. Connolly.

I would place second in importance the results shown by the heating tests described on pages 54 to 56, and also further experiments made by Professor Schwartz on compounds with definite percentages of indiarubber in their composition, which I think prove beyond doubt that by subjecting samples to a heat of between 70° and 100° C., or any convenient heat below the melting-point of sulphur, for several days, and examining the fall in their elasticity and strength, it will be possible to foretell their comparative durability, and to place them in the exact order of their merit.

The so-called Admiralty heating tests are quite misleading and ought to be abolished. It is a physical impossibility for the ideal cable covering having a layer of unvulcanised pure indiarubber without any trace of sulphur next to the wire to stand this test, as this rubber becomes permanently soft, at a much lower heat, while if the pure indiarubber is vulcanised, which is not really as good, it may pass the test.

With respect to chemical tests, I do not place any reliance on the author's recommendation. The only simple and reliable test that the average person can carry out is the ignition test, which determines the approximate amount of mineral matter in a compound. All other tests should be left to the chemist expert in examining indiarubber, and even his deductions should be regarded with a large amount of reserve. For instance, the acetone tests will not determine, as the author thinks, whether Para rubber has been used or not. It is quite possible to adulterate very largely with vulcanised oil substitutes, which are not soluble in acetone, and so obtain a fictitious result. Mineral oils that may have been used in the manufacture of recovered indiarubber, some oxidised oils, and free sulphur are all soluble in acetone; the time recommended of five hours is not sufficient to extract all the soluble matter in many cases. The whole matter is so complicated that it does not appeal to the man in search of simple and reliable tests.

With respect to insulation tests, I think that the Institution test of exposing the cord for a limited time to the vapour arising from boiling water and then subjecting to pressure is of no use whatever, as quite inferior material will pass the tests easily. I think that we should make up our minds to dispense altogether with insulation tests for conductors insulated with lappings of pure indiarubber, and rely upon other observations in determining their quality. Tested dry, the results are

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Mr. Connolly.

quite unreliable, and immersion in water not only lowers but permanently destroys the insulation on account of the creeping of water between the layers, which moisture cannot subsequently be removed.

Flexibles with vulcanised indiarubber should be tested under water before finishing, in the same way and with the same care as wires and cables, and both an insulation and a pressure test should be used. It is our invariable custom to test flexibles in this manner, and we find that the insulation of a covering free from faults actually improves after prolonged immersion.

In talking of pure indiarubber, there is a good deal of confusion, both in the author's paper and elsewhere, in distinguishing whether vulcanised or unvulcanised indiarubber is meant.

There is very little unvulcanised pure indiarubber used nowadays in covering wires, probably none at all for flexibles; the rubber is always more or less toughened or surface vulcanised by the cold cure process, and it is for the manufacturer to determine the best thing to use in this respect. I do not think the author's hysteresis loops will be of any use in this direction. The best thing the user can do is to see that a substantial thickness has been used in at least two layers put in with a moderate tension, and that the layers are fairly adhesive to one another and do not unwrap or fly back when the outer coverings are removed.

With respect to some of the general questions raised in the author's paper: damage to workshop flexible by the use of oily waste can be provided against, as we can easily provide a flexible covering that is oil-proof.

We always nowadays twist or strand the fine wires used in making up flexibles, and never use straight wires.

We are now making a flexible cover with an indiarubber tube in place of the usual fibrous outer covering; we consider that this tube prevents the indiarubber actually used for insulating purposes from being exposed to external influences and prevents the possibility of electric osmosis. It will also act as a flexible substitute for iron pipes in a waterproof system.

I have no doubt that the gymp flexible, as described by the author, will be very useful in special cases for running over small pulleys, but its use will be limited on account of its relative low conductivity and consequent loss of voltage if a long length has to be used. With respect to the bending tests, I am of opinion that flexibles having a double braid, the first braid being of soft cotton, would give results very superior to flexibles having only one braid. The cotton covering next to the wires has been dispensed with in the C.M.A. vulcanised flexible, as it was considered a potential source of danger in attracting moisture to the strands and did not serve any essential purpose.

With respect to tying knots in flexibles, inside the ceiling roses and elsewhere, I think this a great mistake and should not be allowed. It is putting an unnatural and permanent strain on the covering, and other means ought to be found to support the flexible and keep the strain off the terminals. With this object in view we have devised a nipple of

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soft indiarubber that will answer the purpose and at the same time effectually seal the entrance to the ceiling rose. Mr. Connolly.

I quite approve the suggestion of the author that the system of surface wiring with flexibles so much in vogue on the Continent could be used with advantage here, as whatever dangers may be latent in such a system the results are always plainly visible, and can accordingly be remedied without any delay.

In conclusion I may say that provided the limits of the physical properties of indiarubber are properly understood and a fair amount of common sense used in their application to installation work, very few cases of failure can arise. I would also observe that to ensure reliable results, even with the best of materials, great care and skill has to be exercised in the manufacture of such goods, and we are driven to the conclusion that the buyer's principal safeguard is, after all, to rely upon the services of old and experienced manufacturers who, for the sake of their reputation, will take good care that the goods they supply are suitable for the purposes they are intended for, and not to tie their hands too much by imposing rigid conditions that, however excellent they may be, do not cover all, or even the most important, of the precautions to be observed.

Mr. C. BEAVER (*communicated*): Excellent as the paper generally is, and ingenious as some of the deductions are, it will be apparent to those intimately connected with the manufacture of flexibles, insulating rubber, etc., that there is a certain lack of intimate knowledge of manufacturing conditions and details which slightly detracts from the value of some of the conclusions arrived at. With regard, for instance, to the matter of the conductivity of small stranded conductors: in Table IV. the S.W.G. diameters of 36 and 38 strand wires are compared with the diameter of tinned wires (presumably measured), and the difference is assumed to represent the thickness of the tin coating. That this assumption is erroneous will be apparent to any one who is accustomed to make, test, and use tinned copper wires, and could easily have been checked by analytical estimation of the tin, or similar means to which I need not now refer. A simple calculation would then show the actual thickness of tin to be unmeasurable. Mr. Beaver.

May I remind the author that the "lay" or pitch of the copper bar which is shown wound around another bar in a close helix in Fig. 3 (and consequently the P.D. between the two bars), is very different from the "lay" of a strand and the P.D. between the wires comprising that strand.

With reference to the remarks in section IV. on "Insulation of Flexibles," I should like to correct the impression given by the author that "cut" strip rubber is the most expensive and generally used strip for high-class cable work. It is neither the one nor the other.

With regard to the author's remarks as to pure rubber insulation withstanding immersion in water, this is largely a matter of the time elapsing between manufacture and the experiment. The pure rubber becomes firmer and more homogeneous in course of time, and the

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Mr. Beaver. overlaps become closely sealed up by the natural adhesive properties of the rubber applied under tension.

In several statements on the subject of vulcanised rubbers the author is at variance with facts. Fifty per cent. of sulphur, for instance, is only approached to any extent in ebonite work.

With regard to the "jacket" and "separator" reference. This is hardly modern practice, especially when the former contains 10 per cent. of sulphur.

The author's notes on "Oxidation of Rubber" remind one that, conversely, the rate of oxidation under certain accelerated and controlled conditions may be advantageously used as a guide to the comparative durability of rubbers, etc.

As regards the coefficient of vulcanisation and the deductions which may be drawn from it, the author has apparently overlooked the fact that vulcanised rubbers used for insulating purposes may contain mineral substances, such as litharge or magnesia, which have a considerable effect on the coefficient of vulcanisation. The use of such substances is quite legitimate, and although they tend to give a high coefficient, it is certain that the durability of the rubber is not impaired, but improved by them if used in correct and limited proportions.

The standard hysteresis loop suggested by the author is in principle more scientific and thorough as a test than the elongation test which is sometimes specified, but I cannot agree that good behaviour under this test, even when the sample shows a reasonably good insulation test, indicates durability. It is possible to insulate flexibles with rubbers which will comply fully with stretching and other mechanical tests and give a fair insulation resistance, but will be the reverse of durable. A certain type of foreign flexible is a good instance of this. The pure rubber layer is made from an inferior brand of raw rubber, and has a remarkable degree of elasticity imparted to it by vulcanisation with chloride of sulphur. A thin layer of low grade vulcanising rubber is applied over this, and has the mechanical support of the very elastic rubber beneath it. Consequently, it appears to be durable if judged by mechanical tests, whereas in use it proves to be the reverse.

Cable makers in this country will take exception to the statement that the pressure test usually specified for flexibles is very rarely carried out in practice; and the author will be pleased to know, with reference to his opinion that C.M.A. vulcanised flexibles should have the high-voltage test applied after immersion in water, that this is standard practice and has been so ever since such flexibles were first made.

With regard to the author's remarks under the heading of "Testing of Insulation," the simple chemical tests and determination of percentage of ash are, taken by themselves, almost futile, and a fairly complete analysis is often wide of the mark in its results and interpretations thereof, unless made by a specialist. Even such an one would need much bracing up to agree with the author that the amount of acetone extract "may always be taken as a safe guide as to whether the sample has been manufactured from Para or not."

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Mr. Beaver.

Referring to the author's tests on the rubber insulation of flexibles by blowing out the tube of insulation with a bicycle pump, it is, perhaps, only to be expected that when tested to destruction in this way, that the longitudinal joints would fail first, but for all practical purposes the "longitudinal method," as it is called, of applying the vulcanising rubber to small sizes of wire is very efficient. In large sizes it is admittedly less efficient, and lapping methods are generally used in this country for medium and larger sizes of cable.

In conclusion, let me add that makers of good flexibles, etc., in this country would be only too delighted if the author's future work produced some simple series of tests by which easy comparisons could be made by buyers. At present they suffer from the lack of *simple* means of demonstration of the superiority of their goods.

Professor Haldane Gee.

Professor W. W. HALDANE GEE (*communicated*): The author's experiments show that much work requires to be done before we are adequately acquainted with the physical properties of rubber. The hysteresis loops are especially interesting, and suggest a means of distinguishing the varieties of rubber. It would be of value to extend the observations both to higher and lower temperatures. There should not be much difficulty in designing an apparatus to record automatically the loops. Shedd and Ingersol* have shown that the energy dissipated per cycle due to viscosity falls rapidly with rise of temperature. What happens as the temperature is decreased deserves further investigation. Joule,† in his researches on "Some Thermo-dynamic Properties of Solids," mentions "the curious fact that a piece of indiarubber, softened by warmth, may be exposed to the zero of Fahrenheit for an hour or more without losing its pliability, but that a few days' rest at a temperature considerably above the freezing point will cause it to become rigid."

A substance like rubber can have no definite melting point. I have heated Para-sheet for long periods at 100° C. without much softening when determining the specific heat of this substance,‡ and I have lately studied the influence of a gradual increase of temperature on spread-sheet rubber. The rubber was heated in an air-bath. The following figures show the gradual change :—

Temp. °C.		Condition of Rubber.
90–100	...	Very slightly sticky to the touch.
145	...	Sticky, but retains some elasticity.
150–160	...	Surface melts and the rubber darkens.
170–190	...	Gradually melts.
240	...	Can be mixed up and the thermometer easily pushed into the mass.
245	...	Like a thick lubricating oil.
255	...	Appearance of decomposition and boiling.
340	...	Gas evolved which burns with a luminous flame.

* *Physical Review*, vol. xix., 1904, p. 114.

† *Phil. Trans.*, vol. cxlix., 1859, p. 91.

‡ Gee and Terry, "Studies from the Physical and Chemical Papers of the Owens College," vol. i. p. 58 (1893).

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Professor Haldane Gee.

The liquid obtained on heating becomes viscid on cooling, but it does not again solidify. It is useful for lubricating stop-cocks.*

The course of the changes on heating depend on the rate of the application of heat, and appear to be modified by the action of air and light.

Mr. Lamb.

Mr. F. LAMB (*communicated*): Whilst much time and care has been devoted to standardising the quality of wires and cables, flexibles have been left pretty much to take care of themselves, with the result that what is at present very largely being used is a foreign made vulcanised flex, the word "rubber" being fortunately dropped, for very little of this material enters into its composition. The mysterious compound is squirted on to the wire through a die, and whilst plastic and flexible when new soon becomes hard and brittle, breaking up and becoming very little use as an insulator.

These remarks only apply to the foreign made flexible so commonly used, which none of the British manufacturers will make. The vulcanised rubber covered flexibles of British manufacture (which are doubtless the samples from which the author has made his experiments) are of a different order, and whilst in my opinion they are very suitable for use in situations where exposed to the weather or very damp places, or where exposed to rough usage, yet for the majority of uses to which flexible cords are applied, such as pendants, wall plugs, etc., I am distinctly of the same opinion as the author and Mr. Sparks, who spoke on behalf of the Wiring Rules Committee, that pure rnbber insulation is decidedly better than vulcanised rubber. Hitherto the difficulty has been to point to any standard specification which will insure a reliable pure rubber flexible. This deficiency, however, has now been removed, so that the following statements in the paper are incorrect:—

Page 37. "The Vulcanised Rubber C.M.A. flexible, which is the *only standard* material on the market."

Page 78. "As things stand at present the Cable Makers' Association *only make* 'C.M.A.' flexibles *in vulcanised* rubber."

The Wiring Rules Committee of the Institution as pointed out by Mr. Sparks, give a specification for pure rubber flexible (see Wiring Rules, I.E.E., July, 1897, page 5, also revised edition, April, 1907, page 11), and this has been embodied in a specification, adopted by the C.M.A., which is as follows:—

ASSOCIATION PURE RUBBER FLEXIBLES.

Conductors.—The conductors to be of annealed, high conductivity, untinned copper to the standards of the Engineering Standards Committee, and of the same sizes as the vulcanised C.M.A. flexible, viz.:—

* Mr. Baumbach tells me that a mixture for the purpose that is well known in the glass instrument trade is made by heating vaseline to 200° C., and adding small pieces of pure rubber and a little beeswax. It is also useful for applying to ground glass joints.

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Mr. Lamb.

23/36s	equal to	No. 20
40/36s	„	No. 18
70/36s	„	No. 16
90/36s	„	No. 15
110/36s	„	No. 14

The conductor to be covered with one lapping of cotton of 4 mils. radial thickness, then two lappings of pure Para rubber laid on in opposite directions; the total minimum radial thickness of rubber being 20 mils., then two lappings of cotton laid on in opposite directions, each lapping to have a radial thickness of 6 mils., giving a total radial thickness of cotton lapping over the rubber of 12 mils., then braided silk or glacé cotton.

Weight of Rubber in grains per yard of Single Conductor.

L.S.G.	Grains.	L.S.G.	Grains.
23/36	35	90/36	60
40/36	40	110/36	70
70/36	50		

This was placed upon the market last month. It will be seen that the C.M.A. specify the actual thickness and weight in grains per yard of the rubber which should be employed upon this flexible. This is practically as far as the specification can be taken, it having been found impossible, so far, to specify the quality or grade of pure rubber, each manufacturer preparing it in the way he considers best, and upon which his reputation has been made. There is no doubt that in this, as most other things, something must be left to the experience and reputation of the maker.

Mr. Healy.

Mr. L. T. HEALY (*communicated*): I agree with the author's opinion that the flexible is the weakest part of an installation. I have found it to be the cause of a large number of electrical fires into which I have made inquiry, and it can undoubtedly become a source of danger to the person through the falling of heavy counterweights and clusters, owing to the severance of the conductors. The whole subject is a very important one, and up to now has been much neglected. There are many contractors who install quantities of flexible of doubtful quality, and comfort their consciences with the thought that it will all be protected by the fuses, forgetting that there are plenty of consumers who are, unfortunately, prone to replace their fuses by such things as pieces of bottle wire. With regard to the effects of bending, I may mention a case which recently came under my notice where some fifty counterweight fittings in an office building rapidly began to fail after about two years' use, the breakage occurring in every instance close to a pulley wheel. The flexibles were of the thin vulcanised class, and upon examination I found the rubber to be in good condition, but the conductors in the parts of the cord which had been most frequently passing over the pulleys were in very bad condition, the strands being not only brittle but in some cases broken up into short pieces. Most of the failures appear to have started by an

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Mr. Healy. arcing between these broken strands and not by a short circuit. I have never found anything suitable for counterweights except pure rubber insulated flexibles of the best possible quality. The greatest amount of bending at lamp-holders is, in my opinion, caused through the use of switch lamp-holders. Mr. O'Gorman has referred to paper mills, and in such places I do not think flexibles should be used at all as I am not aware that, so far, any form of protection has been devised which will effectively resist the attacks of chlorine for even the most heavily insulated of cables.

I do not quite agree with the author's opinion that pure rubber insulated flexibles are best suited for high temperatures. I recently examined some workshop flexible of that kind which had been subjected to a temperature of 98° F. for about twelve months in a linoleum factory, and I found that the rubber had entirely disappeared, the cotton being quite dry. As is usual in such works, there was much acrolein present, and this may, perhaps, have helped to bring about such a rapid deterioriation.

Professor Schwartz. Professor A. SCHWARTZ (*in reply*): With regard to the relative deterioration of copper conductors insulated with pure rubber and V.I.R., and Mr. Whalley's contention that the hardening effected in the stranding and insulating of conductors can easily be greater than any change due to the presence of sulphur, I would point out that the results given in Table IX. are only a selection from some forty examples which were examined in detail, and that some further examples are given in Appendix E. A consideration of these shows that in nearly every case the conductors have been attacked by the sulphur, and this is evidenced by the discolouration and the brittleness of the outer wires of the strand, whereas with wires insulated with pure rubber this discolouration is absent.

The reason for the temperatures attained by bare wires being higher than those reached with insulated wires in the same time with a given current is to be found in the fact that the cooling surface of the insulated wires is much the larger, and that the insulation itself has a considerable capacity for heat.

With reference to the relative merits of a chemical test, such as that for acetone extract and the stretching test, I have given under Section X., on the "Testing of Insulation," some particulars of the acetone test, as this test is frequently specified both in this country and abroad, but I do not recommend it, as I am strongly in favour of a stretching test in conjunction with a deterioration test at a moderately high temperature.

I hope that further work on the latter lines may enable standard limits to be specified for these tests for given grades of insulation within which limits the results would be regarded as satisfactory. Such a test might replace several of the tests now in use which frequently call for conflicting properties in the material, and would thus be advantageous to manufacturer and purchaser alike.

That the specification of some such limits may not be impossible—

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Professor Schwartz

in spite of the forty varieties of Para mentioned by Mr. Whalley, each with its own temperature coefficient—may be gathered from a consideration of Fig. 12, in which C.M.A. flexibles submitted by four firms, and no doubt differing very widely in the constituents of their compounds, fall within limits which differentiate them from the non-association wires and from the samples sold as being "equal to C.M.A. flexible."

The coefficient of vulcanisation is the percentage ratio between the amount of indiarubber and sulphur of vulcanisation present, the addition of such substances as litharge or magnesia, as stated by Mr. Beaver, may have a considerable effect on the state of vulcanisation, but they cannot affect the ratio referred to above. With regard to the state of vulcanisation, I am of opinion that this can be best determined by the hysteresis test, but I think that the more general use of the "vulcanisation coefficient" in specifications would be an advantage as at the present time it is often impossible to tell whether the percentage of sulphur specified is to be calculated on the total contents of the compound or on the rubber contents only.

With regard to the use of cut sheet, I understand that the enterprising foreigner has placed in our markets rolled sheet which is passed between rollers cut so as to imitate the cut marks on cut sheet; apart from this material, however, I believe "rolled" sheet is now largely used.

Mr. Beaver states quite correctly concerning this paper that it is apparent to those intimately connected with cable manufacture that there is a certain lack of intimate knowledge of manufacturing conditions and details which detracts from the value of some of the conclusions arrived at. Any one who, like myself, is outside the rubber industry, will appreciate the difficulty of obtaining such information, as the "trade secret" still looms very large, and inquiries as to details of processes meet with polite but firm refusal.

The 50 per cent. of sulphur referred to by two speakers was instanced as the upper limit for sulphur employed in manufactured indiarubber, and as inferred refers to ebonite.

I am interested to learn from Mr. Lamb that the Cable Makers' Association have placed a standard pure rubber flexible on the market, and trust this material will meet with an extended use.

Pressure should be brought to bear on the manufacturers of ceiling roses, switches, etc., to ensure that the holes in the porcelain are large enough to take the increased thickness of insulation on first-class material; this fact in the past has largely limited the use of C.M.A. flexible, and encouraged the employment of inferior material with thinner wall. This is particularly desirable in view of the extension of the use of flexibles to wiring systems.

The PRESIDENT: I will now ask you to accord to the author a very hearty vote of thanks for the exceedingly useful and valuable paper he has given us to-night.

The resolution was carried with acclamation.

The meeting adjourned at 9·35 p.m.

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CAPE TOWN LOCAL SECTION.

ELECTRIC LIGHTING OF TRAINS.

By JOHN DENHAM, Member.

(*Paper read July* 23, 1906.)

Early experiments, conducted about twenty odd years ago, in the electric lighting of trains on the Cape Government Railways consisted of a steam-driven dynamo installed on the locomotive. This was obviously incomplete, and was speedily abandoned. The problem was first seriously tackled in 1888, when a Wynberg train of six or seven carriages was wired on the through two-wire system, the current being supplied by fifty small flat E.P.S. cells, two sets in parallel, fixed in cupboards in the van. Each compartment was provided with a 10-c.p. 50-volt lamp, fixed horizontally in front of a concave nickel-plated reflector, and the whole fitting was not more than 3 ins. deep. This was a great advantage in those days, when the carriage roofs were much lower than they are now, and when the old colza-oil well used to project nearly a foot from the roof. The fitting up of the original train and the charging arrangements, which consisted of a 1½-k.w. dynamo fixed at Salt River Works, were carried out by the then electrician to the Harbour Board, Mr. John Melville Smith, with the assistance of Mr. Wadman, who is still with the Harbour Board.

The batteries for this train being placed in the van portion of a first-class carriage, it was necessary for the vehicle to be kept many hours in a siding during charging operations, and, to minimise inconvenience to the Traffic Department, a second van was fitted up with batteries so that it might take the place of the other during charging periods. This, however, necessitated withdrawing a bogie passenger vehicle permanently from traffic; consequently, when it was decided to extend the electric lighting, the accumulators were fitted into short vans and only attached during the night-time.

For several years a charging plant existed in Salt River Works, capable of charging six or eight sets of cells at a time, but owing to the time occupied in shunting the accumulator vans between the works and Cape Town, it was decided in 1894 to instal a larger charging plant in

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Cape Town station yard. This consisted of two 350-ampere Edison-Hopkinson machines, driven by a Davey-Paxman horizontal compound engine of 120 I.H.P., and circuits were run underground to a number of fixed points in a carriage shelter that then existed alongside the Parade wall, into which the vans were shunted. For convenience in handling, it frequently happened that the last van to be shunted in, and the one that had had the least charge, was the first one to be drawn out. The vans, of which there were fourteen or sixteen, were fitted with 25, 23, L., or 31, L., E.P.S. accumulators in teak boxes, lead-lined and provided with lids. (Weight, 3½ tons.)

A few sets were fitted into bogie vehicles, as at that time the mail train to Kimberley and the portion round to Port Elizabeth were electrically lit, there being two separate sets of cells in parallel on this train, which were recharged at Kimberley and Port Elizabeth respectively, and recoupled up again at De Aar. The electric couplings now fitted are the same as those then in use. They are double pole, but not male and female—that is, both halves are alike; consequently whenever two come together they can be connected. Great care was taken in wiring all the carriages, so that when the positive cable had its ends on the same end of the carriage, one half coupling faced upwards and the other downwards, or *vice versâ*, if the main cable were crossed. By similarly following out a uniform system in connecting up accumulator vans, it was impossible to connect up any two accumulator vans otherwise than positive to positive and negative to negative, no matter how few or many vehicles intervened between them or how these may have been turned round in the ordinary course of traffic. Also, as the charging cables at the various stations ended in similar couplings, no thought was required to connect up correctly; it was simply necessary to couple up either end and in the only way they would fit, and they were bound to come right. The saloon carriages having through communication, two pairs of wires and couplings were necessary at each end, so as not to obstruct the central passage. The cables were only duplicated at the ends, and whether these short lengths were electrically connected or not made no difference.

When the line was opened to Johannesburg about 1894, the mail service between Cape Town and Port Elizabeth and Kimberley was discontinued, and fast trains were run to the Rand instead. In those days the trains were much shorter than they are now, and with care 500 ampere-hours would carry a train right through, the cells being recharged at Braamfontein. This necessitated a spare van at the far end to ensure time for a full charge, but even with this the recharge, owing to difficulties and delays due to shunting operations, were often incomplete. Although various kinds of cells were tried, amongst others the E.P.S., lithanode, chloride, I.E.S., and D.P., none of them retained anything like their normal capacity. Another difficulty encountered was the breaking off of the lugs. They projected through tapered holes in the wooden lid, and had rubber washers to prevent the splashing of acid. It was found that

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the positive lugs became oxidised and swelled up enormously, so much so that they split the lids sometimes. The swelling scaly oxide was, of course, formed at the expense of the metallic lead, and consequently the lug itself was so weakened that it broke off with the vibration. It was found necessary to leave a perfectly clear air space round each lug to prevent any action taking place across the under side of the wet lid.

The next step was the introduction of oil-engine-driven dynamos, without any accumulators as reserve. The Hornsby-Ackroyd oil-engine was selected as being most suitable, and many years of experience have since confirmed the opinion. It was recognised that any oil-engine that depended for its operation on a flame-heated ignition-tube was unsuitable, as the wind might extinguish the flame, even if it did not often go out through the spray-hole being choked.

The engines, of which twenty-five are still in use, are of 3½ nominal H.P., and give up to 5 B.H.P. The dynamos are rated at 40 amperes at 52 volts, but generally give more. While those machines were capable of lighting an ordinary local train of six or seven carriages, they are not powerful enough to cope successfully with the eight- or nine-carriage trains now standard on the Wynberg and Simonstown line. Others more powerful and having two cylinders arranged vertically were then introduced, but these were not a success. One difficulty in connection with the working of oil-engines on long-distance main-line trains is due to the great variation of altitude, from 0 to 6,000 ft. above the sea-level; this necessitates some method of adjusting the explosive or altering the cubic contents of the explosion-chamber to effect the same purpose. The horizontal oil-engines give little trouble and need few repairs. We have had several in use for ten years, and they are still giving satisfaction. Ordinary paraffin oil is used, as it was found to be as good as and cheaper than any of the special oils recommended by the makers, also it is not desirable to increase the variety of oils in use. The consumption is about 1 pint per B.H.P. per hour, costing 1d.

One or two experiments were tried some years ago as to the lighting of individual coaches from the axle, but the system was not sufficiently developed to be a success. An endeavour has been made, therefore, to improve upon methods of supplying the necessary electrical energy from one source on the train. With this object, and to cope with the heavier traffic, complete steam-engine plants were fitted up in an end compartment of 12 bogie vans.

Latterly, however, the Rhodesia Railways and the Central South African Railways are running their own coaches on the Cape Government lines, and these are mostly fitted with Stone's patent lighting system, in which each vehicle is separate; but although this system possesses many advantages over the single source of supply, it was not considered advisable to recommend its adoption to our rolling stock, first on the score of expense, as it would mean discarding the existing electric fittings, cables, couplings, etc., on hundreds

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of saloon carriages, and the additional cost of a new system; and, secondly, our lines are so extensive that vehicles would be largely out of reach of proper supervision, and consequently could hardly be expected to operate satisfactorily. As a compromise, the patentees of Stone's system were approached to see if they could adapt their apparatus for lighting a whole train. Unfortunately the largest gear they manufactured could only deal with, at the most, one half of a normal train, so it was decided to fix up two dynamos and accessories and run them in series to obtain the voltage requisite for our lamps and standard wiring, namely, 50 volts. This has been done in the case of five vans with a fair measure of success.

The essential features of any system of train lighting, in which power is taken from the axle, are as follows:—

(1) The voltage and current from the dynamo must not exceed a predetermined amount irrespective of any increase in the speed necessary to produce that amount.

(2) Means must be provided to alter the connections between the armature and the cells when the direction of rotation is reversed.

(3) Means must be provided to connect the cells to the dynamo when the latter is capable of charging the former, and *vice versâ*.

(4) Adequate storage capacity, which generally takes the form of accumulators, must be provided to deal with periods of rest or slow running.

It will be noticed that so long as the dynamo revolves in one sense and the lamps are on, so long is there more or less resistance between the two sets of cells, consequently (*a*) gets the most charging and (*b*) gets the most discharge. This has also been proved by tests carried out here with ammeters in all circuits.

The operations of switching in and out can best be seen by inspecting the complete diagram of the actual connections (Fig. 1).

The apparatus supplied for some of our railways consisted, as previously mentioned, of two sets of Stone's apparatus arranged in series; therefore there are two dynamos and four sets of cells.

The disadvantage of this method is that if one half of the arrangement failed from any cause, it would disable the whole. For this reason the dynamo would have been better arranged in parallel instead of in series.

Recognising this difficulty, among others, experiments were carried out with an ordinary 4-pole G.E.C. dynamo, which was erected on a rocking table in a van so that the belt-slipping principle could have full play. The machine gave the full voltage for charging up twenty-eight cells and current enough (100 amperes) to charge two sets at a time.

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The requirements were fulfilled as follows:—

(1) The output was limited by the driving power of the belt.
(2) The alteration to connections between cells and dynamo was effected by the very simple expedient of having the brush rocker quite loose; so that the friction of the brushes was sufficient to carry the rocker round the necessary

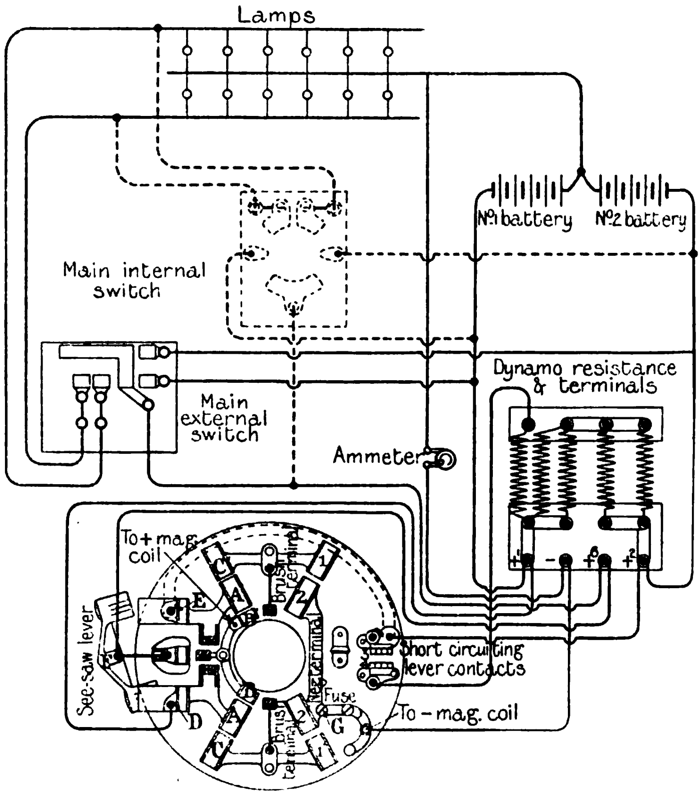

FIG. 1.

quadrant until arrested by a stop. This works excellently in practice.
(3) The connection between cells and dynamo was effected by an automatic magnetic switch provided with a dash-pot and carbon breaks, and the forward motion of the movable limb was made to introduce a resistance in the lamp circuit simultaneously with the making of main contract and consequent rise of pressure.

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(4 and 5) The cells, of which there are fifty-six, each of 250 ampere-hours capacity, are arranged in two sets of twenty-eight in parallel, with a resistance between them as in Stone's system.

The two sets, however, are connected to a switch in such a way as to enable their relative electrical position to be altered as often as required by hand, so as to equalise the work between them.

This arrangement was found to work well, although much difficulty was experienced with the main driving belts owing to the fact that the driving and driven shafts vary by as much as 13° from the parallel, it being necessary for several reasons to adopt a countershaft drive.

It was considered, however, that as the rocking cradle corresponded rather closely to the hanging dynamo of Stone perhaps a fixed dynamo would do as well. This was tried, and the present arrangement is to have a dynamo fixed in a sliding bed-plate in the usual manner. One selects a belt of suitable breadth and texture for the work, and by varying the tension by means of the tightening screws, it is easy to adjust to not more than any selected output, say from 50 to 120 amperes. The resistance between the two sets of cells was made adjustable to choke back more or less volts as the output was small or great.

Owing to the necessity of having an attendant to deal with the reversing cell switch and the adjustable resistance, and other drawbacks, I devised and patented a modified scheme, employing only one set of cells. This has now been taken over by Messrs. Stone and Co., who are supplying an experimental set for use on the Cape Government Railway. The description and drawing given in the patent specification will enable the working to be clearly understood. In train-lighting installations to which the invention is applicable, the primary source of current is a dynamo driven from the axle of the carriage, while a storage battery is provided to maintain the potential of the lamp circuit when the dynamo is not running or is being driven at too low a speed for the purpose.

Preferably the apparatus is arranged so that either the whole train of carriages is supplied by means of a single dynamo in conjunction with a single battery of storage cells mounted on the same carriage, or else each carriage is independently lighted by a separate dynamo and separate battery carried thereon, but the apparatus may also be applied to the case in which there is a single dynamo for the whole train with separate storage batteries for each carriage.

In any case, according to this invention, there is the same provision made for the driving of the dynamo or dynamos for securing constancy of polarity of the dynamo with respect to the storage battery with which it co-operates, constancy or approximate constancy of voltage on the lighting circuit or circuits, and for automatically switching the dynamo or dynamos into and out of the circuit in accordance with the speed of the train and the voltage of the circuit; and for the purpose

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of illustration the invention will be described with reference to the arrangement in which each carriage is separately equipped as an independent unit.

In addition to the devices provided for securing these results, the invention also includes other specific controlling and regulating apparatus, which are illustrated in the accompanying drawings, of

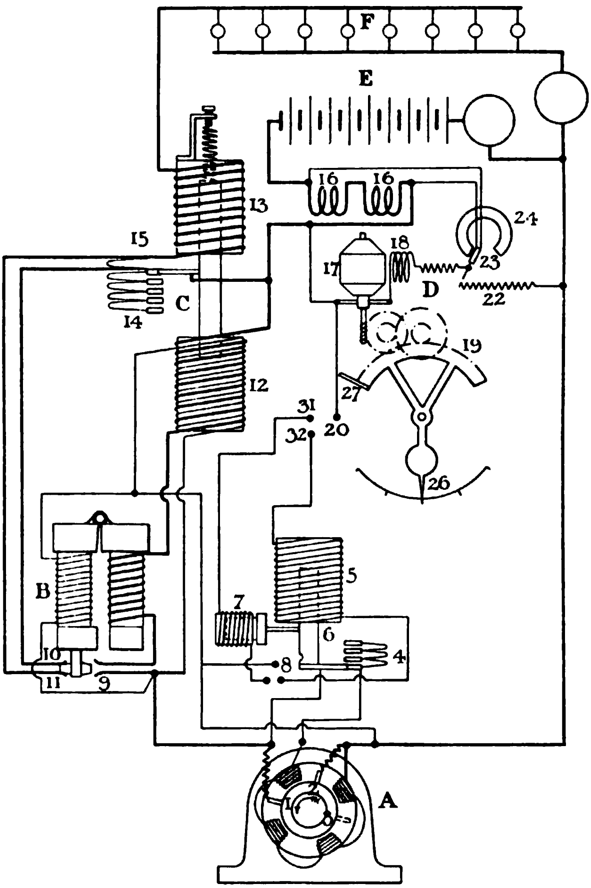

FIG. 2.

which Fig. 2 is a general diagrammatic view of the whole apparatus; Figs. 3 and 4 are diagrammatic views of the dynamo-field controlling device in two positions; Fig. 5 a detail view of the preferred form of automatic rheostat; Fig. 6 a detail diagram of the automatic cut-out device when it is combined, as sometimes preferred, with the dynamo field-magnet system; Fig. 7 a detail

of a flanged axle or pulley for driving the dynamo by means of a belt; and Fig. 8 a diagram showing the application of the apparatus to the case in which there are separate storage batteries for the various carriages of a train, but only one dynamo for the series.

Referring to these diagrams, the dynamo A is an ordinary modern

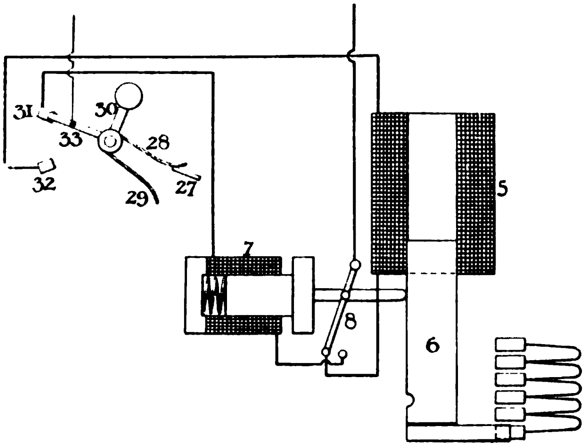

FIG. 3.

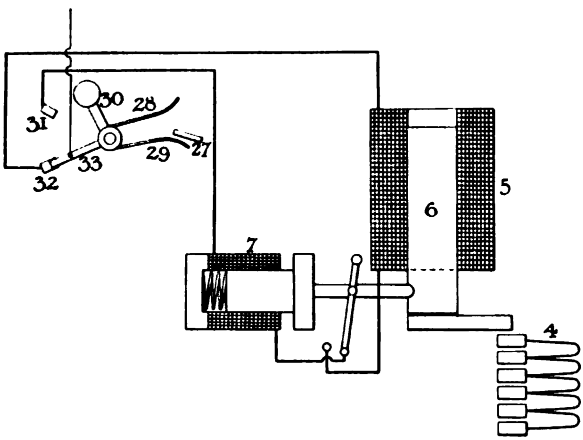

FIG. 4.

shunt-wound machine, preferably of the multipolar type, having good voltage regulation, and of the enclosed pattern if intended to be fixed under the carriage. The pulleys on the axle and on the dynamo shaft have bevelled flanges, as shown in Fig. 7, to prevent the driving belt from coming off when the carriage is on a curve. To

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provide for adjustment of the driving-belt the dynamo is mounted on a sliding base or rails, to which it is rigidly secured after tightening the belt to the necessary degree of tension. With a given belt tension the output of the dynamo will remain constant enough for practical purposes when a given speed is exceeded, on account of the slip of the belt. Thus it has been found that the output of

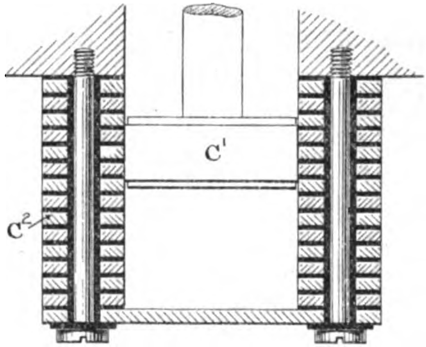

FIG. 5.

the dynamo arranged to run at such a speed as to give no current at a train-speed up to 20 miles per hour and full current at a train-speed of 23 miles per hour will not increase seriously at speeds greater than 23 miles per hour.

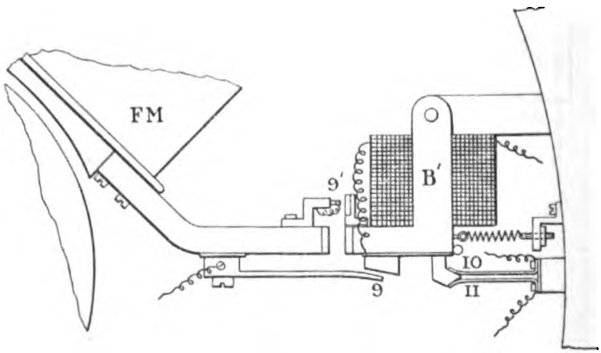

FIG. 6.

The correct polarity for charging the cells irrespective of the direction of rotation of the driving axle is obtained by the well-known device of mounting the brushes so that the friction of the brushes on the commutator carries the rocker through the necessary angle at each reversal of the armature, the limiting positions of the brushes being determined by fixed stops. To ensure certainty of action of this device,

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even with little friction between the brushes and commutator, the rocker may be mounted on ball bearings, but generally this is unnecessary owing to the greater friction, and also to the greater leverage through which it acts, between brushes and commutator as compared with that of the rocker on its supporting ring.

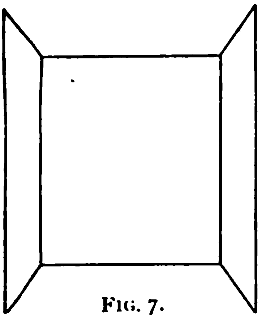

FIG. 7.

In the 4-pole generator shown in Fig. 2 the carbon brushes are set 90° apart, and are carried into the position shown when the armature rotates in the direction of the arrow, and into the position 2, 3 on reversal of the rotation.

A graded resistance 4 is included in the field circuit, controlled by the electromagnet 5, the core 6 of which operates the switch arm. A detent-magnet 7 is arranged to hold up and release the core 6, and also to actuate a two-way switch 8.

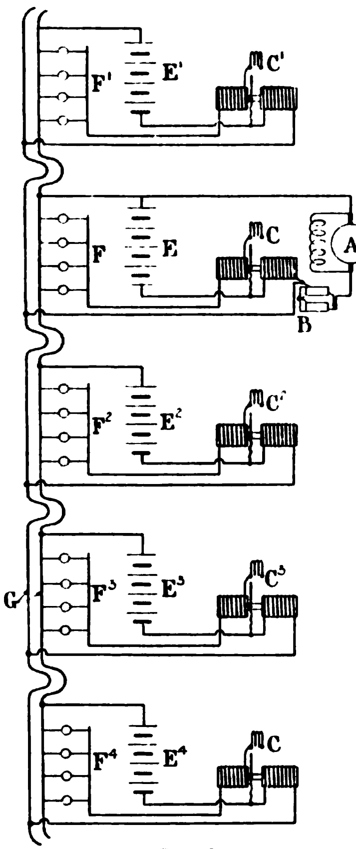

FIG. 8.

The dynamo is switched in and cut out of the circuit by the electromagnetic cut-out B, which controls the main circuit break 9, and also connects the contacts 10, 11, and so short-circuits the resistance 13 when the dynamo is not excited. The main circuit passes from the cut-out to a differentially wound magnet switch 6, having one main winding 12 in the charging circuit assisted by a shunt winding, and a second opposing main winding 13 in the discharge circuit, which also includes the variable resistance 14, controlled by switch 6. From the magnet winding 12 the circuit is continued through the meter O to the storage battery E, and thence back to the generator. The meter O, which is also adapted, as will be hereafter described, to subserve other than its

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normal duty, is of a suitable motor type, having its series coil in the battery circuit with the armature 17 and starting coil 18 in shunt. Geared with the meter armature shaft is a pivoted segment 19, adapted to operate a two-way switch 20, which controls the excitation of the magnets 5, 7.

The lamps F are connected with the cells through coil 13 of switch C, and meter-field coil.

The core or switch arm of the differentially wound magnet C is suspended or balanced, when no current is being generated and no lamps are alight, and the whole of resistance 14 is cut out of the lamp circuit. When lamps are switched on the core is attracted by coil 13, but is prevented by a stop from moving upwards (Fig. 2). When the dynamo generates, the main switch 9 is closed and the auxiliary contacts 10, 11 opened, throwing the resistance 15 into the lamp circuit simultaneously with the closing of the charging circuit. As the excitation of coils 12 opposes that of coil 13 the core is attracted downwards, more or less of the resistance 14 being brought into the lamp circuit, and as the cells become more fully charged the excitation due to the shunt coil of 12 is increased and more resistance inserted. By properly proportioning the different windings of C the voltage of the lamp circuit can be maintained nearly constant, but when very close regulation is required an additional solenoid is employed in the main dynamo circuit which puts in resistances proportional to the charging current.

The condition of the cells is indicated by means of the geared segment arm 19, which carries a pointer 20 moving over a capacity scale, and can be turned on its pivot by the meter gearing only so far as to indicate the full capacity when the cells are fully charged. As soon as any discharge takes place the pointer 26, which is weighted, brings the segment into re-engagement with the gearing, and the pointer traverses the scale in the reverse direction in proportion to the quantity discharged. The scale should indicate zero charge while there is still some charge left in the cells, which may be drawn from them at reduced voltage and must be replaced before any useful charge can be considered to have been stored.

In order to compensate for the loss in conversion in the cells and for the reduced output at heavy discharge, a variable rheostat 22 is concluded in the meter-armature circuit, controlled by means of a switch arm on a moving coil 23, which shunts a convenient part of the discharge circuit, such as the meter-field coils 16, and is mounted in the field of a permanent magnet 24, which may be the meter-brake magnet.

The coil 23 is arranged to move in the direction which cuts out the resistances 22 when the current is in the discharge direction, thus making the meter run faster, and the speed increasing with the rate of discharge.

Even when no current is passing from the cells, it is advisable that the starting coil alone should cause the armature to turn slowly in the

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discharge direction at such a rate as would register complete discharge in, say, a fortnight, so as to allow for the gradual discharge of the cells on open circuit.

The cutting out of the dynamo when the cells are fully charged and cutting in when discharged to a predetermined extent, are effected by means of the two-way switch 26, which is operated by means of the arm 27 on the pivoted segment 19. In Fig. 2 the arm 27, which works between the projecting fingers 28, 29 of the weighted lever 30, 33, throws the switch lever at full charge from contact 31 to contact 32, and the resulting excitation of solenoid 5 and the attraction of the core 6 upwards would cut in the resistance 4 and finally break the field circuit. When the core 6 reaches the latter position, a catch attached to the spring-urged core of solenoid 7 drops into a corresponding notch in the core 6 and prevents it falling again. The same movement of the catch also shifts the switch 8 to connect the coil 7 to the shunt circuit, which, however, is not closed until switch arm 38 is returned to contact 31. This is arranged to occur by properly spacing 28, 29 when the predetermined discharge has taken place, the arm 27 engaging arm 29 and shifting the switch. The coil 7 being now excited, the catch is retracted, allowing the core 6 to drop and at the same time shifting switch 8 to break the circuit of the 7 and close that of coil 5, which, however, is inoperative until it is also closed at 33, 32. By means of this device the generator field can be established and annulled automatically as required, thus avoiding a sudden rush of current on cutting-out resistance if the train happened at the moment to be travelling at a high speed, or the breaking of heavy currents in an inductive circuit.

In order to economise space, the shunt-wound limb of the automatic cut-out B may be dispensed with, as shown in Fig. 6, and the field magnetism of the generator utilised to attract a hinged core B^1, carrying a series-exciting coil and normally retracted by a spring to connect the contacts 10, 11. When the core B^1 is energised by induction from the field magnets it is attracted to close the main contacts 9 and the subsidiary carbon contacts 9^1, which take the spark on breaking the circuit.

The application of the system of lighting to a train having separate storage batteries E, E^1, E^2, E^3, E^4, for the various carriages but only one dynamo A for the whole train is illustrated diagrammatically in Fig. 8.

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NEWCASTLE LOCAL SECTION.

TRAIN-LIGHTING.

By H. HENDERSON, A.M.I.E.E.

(*Paper read February* 25, 1907.)

The lighting of railway carriages has recently been very much under discussion, owing to remarks made concerning fires in accidents presumably caused through the gas used for lighting the carriages. In two recent reports—namely, Catesby Tunnel, on the Great Central Railway, and Grantham—the Board of Trade inspector called special attention to the serious danger from the gas becoming ignited and assisting any fire which may have been started.

The essential points necessary in carriage lighting by electricity are: (1) Each carriage must be independent (except in the case of "block" trains where carriages are grouped to one unit). Such carriages, with their own lighting plant, can travel on any line, no matter how far it may be from a central point, and their lighting will always be available. (2) Lighting must be continuous, thus necessitating the use of storage batteries. (3) Voltage at the lamps must be constant for all speeds of the dynamo. (4) The current must always leave the dynamo in one direction, irrespective of direction of rotation. (5) The dynamo must be totally enclosed to protect it from water and dust.

Nos. 1 and 2 are accomplished by giving each carriage, or group of vehicles, a complete outfit of dynamo, batteries, and all the necessary automatic switchgear to operate the charging and discharging of the batteries, and by bringing into use either the dynamo when its voltage is that required for the lamps, or the batteries when the dynamo voltage falls from any cause whatever. No. 3 is the most important part of the whole arrangement, and is the factor which makes a train-lighting plant very different from the ordinary electrical plant, where constant speed is easily maintained. In the oldest system of self-contained lighting this is obtained by mechanical means, but in the later systems the arrangements are all electrical. No. 4 is necessary, owing to the use of the batteries, and is carried out usually by revolving the brush gear or by working a change-over switch by centrifugal governors, which at the high speeds do not operate. Various forms are used, all after the same principle.

The standard voltage in use is 24, but voltages of 16, 30, and 50 are also in use. The low voltage has been chosen on account of the

vibration affecting the lamp filaments, and also to keep the number of batteries low. The disadvantage of the lower voltages is that for large coaches the current becomes very heavy, rising in the largest sizes to 80 amperes. This necessitates heavy wires, and under present circumstances must add to the cost.

For the maintenance of lighting, batteries are combined in either single or double systems. The former are chiefly used on coaches where all or half the lights are required together, the lamps being wired on two circuits, so that half lights may be used if desired. Since the batteries must be charged up to nearly their full voltage, it follows that, when the dynamo is supplying lamps and charging at the same time, a resistance must be inserted in the lamp circuit to reduce the voltage. As either half or full lights are always on, the value of the resistance can be accurately calculated and set. This arrangement is satisfactory so long as all or half lights are required. If, however, individual lighting is required, as in sleeping or dining carriages, recourse must be had to double batteries, one battery receiving a charge whilst the other floats on the lamps. The latter battery is connected to the main voltage through a resistance which prevents it receiving a charge, and some systems discharge this battery to the lamps in addition to the dynamo current. If a double battery is not used on such carriages, then each lamp or group of lamps requiring to be switched must have a resistance inserted when the dynamo is running, the resistance being cut out when the battery is in use. Such an arrangement is shown in a later diagram.

The prominence given to electric lighting has not arisen without a similar awakening in gas lighting. Owing to the high calorific power of the oil gas used, it is very well adapted to the use of incandescent mantles. Experiments have proved that a highly efficient carriage illumination could be obtained with a very much reduced consumption of oil gas, and although electric lighting of two 8-c.p. lamps gave a higher photometric value than ordinary burners, the incandescent burner was an improvement on the electric light. These values work out as follows: ordinary burner, 4 c.p. to 7 c.p. from corner to centre of compartment; two 8-c.p. electric lamps, 7 c.p. to 12 c.p. from corner to centre of compartment; incandescent burner, 9 c.p. to 14 c.p. from corner to centre of compartment. It will thus be seen that the incandescent burner is a very serious competitor in carriage lighting.

The actual cost of running the two is a much more difficult problem to prove accurately. It is commonly assumed that no extra coal is used in running a train fitted with self-contained electric lighting sets. Sir William Preece, in a report on train-lighting, says: "The efficiencies of dynamos and accumulators and the power taken by electric lamps are absolutely known quantities, and, although coal used per train-mile is necessarily a variable quantity, there will certainly be a constant additional quantity used where electric lighting is provided. Under

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the general conditions of this method of lighting, we are of the opinion that the power generated cannot be less than twice that consumed in the lamps—that is, the total efficiency is about 50 per cent." The efficiency of the lamps does not exceed 3 watts per candle, and, taking an eight-compartment coach with two 10-c.p. lamps in each compartment, the power required to run the lamps is 480 watts, or about 0·64 H.P., giving 1·28 H.P. at the carriage axle if 50 per cent. efficiency is taken. The coal required on such trains usually averages about 2 lbs. per horse-power per hour, and for 1,600 hours, at 8s. 6d. per ton for coal, the cost would work out at 15s. 6d. In addition, the cost of hauling the extra weight of the electrical equipment over the gas—namely, about 10 cwt. per vehicle—would be about 5s. The cost for maintenance of the apparatus varies with different companies—from £4 to as much as £15, whilst the average is about £7 to £9. The higher prices are due entirely to the comparatively small percentage of electrically lighted stock on some of the railways. A firm making this type of plant offer to maintain fifty coaches or over at the rate of £3 19s. 6d. per coach per annum. Taking this figure the annual cost would work out at :—

Electric Lighting.

Interest at 4 per cent. on capital cost	£6	0	0
Annual cost of maintenance	3	19	6
Estimated cost of fuel	1	0	6
	£11	0	0

Ordinary Gas Lighting.

Interest at 4 per cent. on capital cost	£1	18	2
20,900 cub. ft. of oil gas at 13s. 7d. per 1,000 ft., including cost of cleaning, lighting, and repairs, and also capital cost on gasworks, mains, etc.	14	3	10
	£16	2	0

Incandescent Gas Lighting.

Interest at 4 per cent. on capital cost	£2	16	0
7,000 cub. ft. oil gas at 13s. 7d. per 1,000 ft., including cost of cleaning, lighting, and repairs, and also capital cost on gasworks, pipes, etc.	4	15	1
Cost of mantles at 6d. each (six per 1,000 ft.)	1	1	0
	£8	12	1

In spite of this difference, electric lighting has great advantages in local trains running into large centres such as London, Birmingham, Liverpool, and Manchester, where the approaches to the stations are through tunnels. For such trains a magnetic switch, called a distance switch, can be made to operate from a switch in the guard's van, so that all or half lights can be put on for use in the tunnels or cut off when running in the open. Thus a considerable saving can be effected.

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The following are technical descriptions of the different self-contained systems now in use.

STONE'S SYSTEM.

This is the pioneer system of self-contained carriage lighting sets, It was first tried on the Great Northern Railway (Ireland) in September, 1895, and on the London, Tilbury, and Southend Railway in November, 1895, the latter railway having used it from that date for all its carriages. This is the only system in which mechanical methods are adopted for the regulation of the voltage at various speeds above a predetermined value. The method employed would appear to be most unmechanical, yet it has proved quite satisfactory and reliable, and so far, in England, holds the field in this form of lighting. The

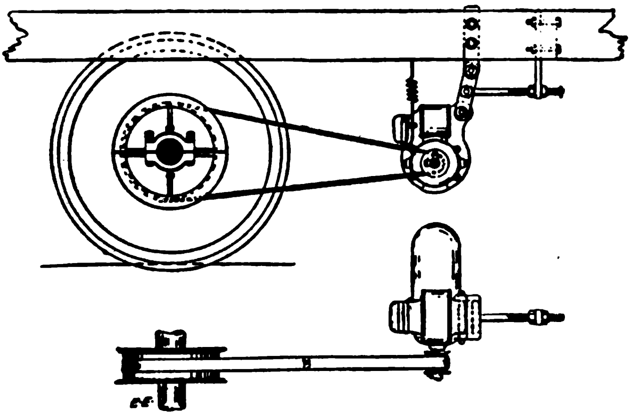

FIG. 1.—Method of Suspending Dynamo.

dynamo is specially hung, as shown in Fig. 1. It is attached by a loose hinge to an adjustable link, which is held in position by two nuts on a tension screw. The dynamo is thus free to swing towards, or away from, the driving pulley on the axle. The suspending link and belt are adjusted so that the belt draws the dynamo out of the position in which it would naturally hang, thus putting a definite tension on the belt just sufficient to absorb power equivalent to the electrical power required. Thus, when the pull on the belt (owing to the increase in the speed) exceeds the weight on the belt due to the one-sided suspension of the dynamo, the latter will automatically be drawn towards the driving pulley on the axle, thus allowing the belt to slip, whilst the armature will continue to revolve at its normal speed. The belt tension can be regulated to suit requirements by means of the tension screw.

This system uses two batteries, and the switching is so arranged

that one battery serves to regulate the voltage at the lamp terminals, whilst the other receives a small charge. When the coach runs in the opposite direction, the connections of the batteries are automatically reversed, and the battery last charged becomes the regulating battery and the other one receives the charge. A resistance is also used in the circuit, which prevents the lamps being overrun, since the dynamo must generate a higher voltage than that required for the lamps. Fig. 2 shows this simply. On the left-hand diagram, with the dynamo

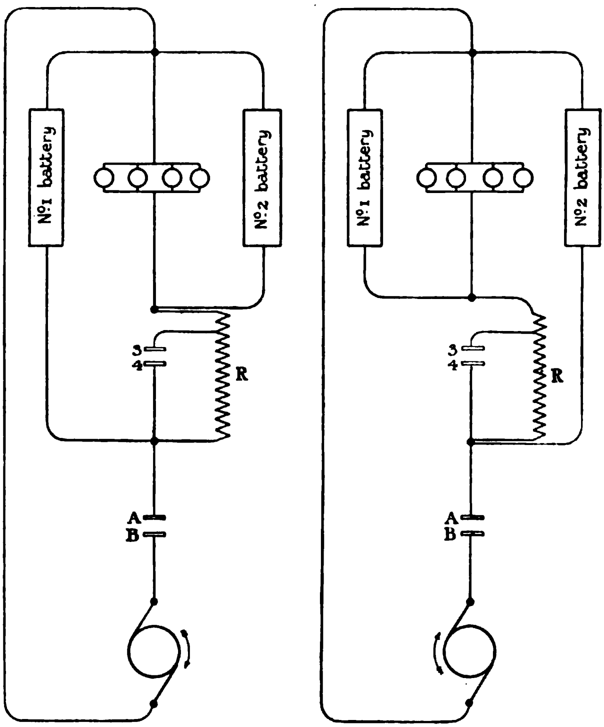

FIG. 2.—Distribution of Current between Dynamo, Batteries, and Lamps.

running, contacts A and B are closed and 3 and 4 open. Current will then flow direct through No. 1 battery and also through the resistance to the lamps, No. 2 battery being directly across the lamps. When the train stops, A and B are opened and 3 and 4 closed, No. 1 battery now supplying part of the current required through 3 and 4, and a section of the resistance and No. 2 battery supplying direct to the lamps. When the train runs in the opposite direction, these operations are reversed. If the train has very long runs in one direction during daylight, the main switch has two extra contacts, so that, when the lamps are off, the resistance is short-circuited, the

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current generated being then equally divided between the two batteries. The automatic switches by means of which the above-mentioned operations are carried out are attached to a switchboard at the commutator end of the dynamo. The main movable contacts are attached to a rocking arm, which is carried round in the direction of rotation as far as certain stops will allow. This rocking arm is attached to the movable part of a centrifugal governor fixed to the end of the armature shaft, and arranged in such a manner that, as the speed increases, the governor opens and pushes the rocking arm along the shaft, closing contacts which connect up the cells, dynamo, etc., in the correct order. The rocking-arm in its motion also changes over a see-saw switch which reverses the operations described and illustrated in Fig. 2. The sliding of the governor also operates a knife switch which opens the contacts 3 and 4 in Fig. 2 and closes the same when the speed falls. This motion also operates a carbon break in the field circuit which saves the contacts on the rocking arm from arcing when the switch is withdrawn by the governor. Fig. 3 shows the actual connections from the switchboard. Supposing the dynamo is running in the direction of the hands of a watch looking at the governor end, the rocking arm will be turned to the right and face contacts C, A, and B and 2 and 1. As the speed increases, the rocking arm contacts will close A (against one side of which it is in contact) to B, thereby exciting the field from No. 1 battery. If the lamp voltage is 24, then, when the dynamo is generating 24 volts, the governors are adjusted to complete the contacts, and C is now joined to A and B and No. 2 to No. 1, at the same time opening contacts 3 and 4, and connecting the see-saw switch to E. Current will now pass from bottom brush through C to A and B. From B it passes round the magnet circuit. From A it passes to D, and on to terminal marked $+^1$ on the resistance terminal board; thence to the positive of No. 1 battery, and, if the lamps are off, part will go through the resistance to No. 2 battery, returning through the common negative to the negative terminal on the resistance board and back to contacts 2 and 1 to top brush. When the dynamo runs in the opposite direction, the rocking arm will be carried over and connected to the other set of contacts. A^1 and B^1 are first joined, then all connections are completed, and the see-saw switch is in D. Current will then flow from the top brush to B^1 and excite the field, and from A^1 to E, from E to 4, from 4 to $+^2$ on resistance board, from this to positive of No. 2 battery, and also through resistance to No. 1 battery, returning through negative to 2^1 and 1^1, and so back to bottom brush. If the lamps are now brought into use, say, in the latter case, current will pass through the resistance from the dynamo to terminal $+^1$, from $+^1$ to D, from D to F, and + on the resistance board, and from this terminal to the lamp switch, and through the lamps by a double circuit back to the — terminals. No. 2 battery will thus receive a charge, and No. 1 will be across the lamps. If the train stops and lights are in use, contacts 3 and 4 are closed as the others open, and thus current passes from No. 1 battery through $+^1$

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to D, and F and + to the lamps, No. 2 battery also discharging through 3 and 4 and part of the resistance to +¹, and over the same route to the lamps. The addition of this resistance compensates for

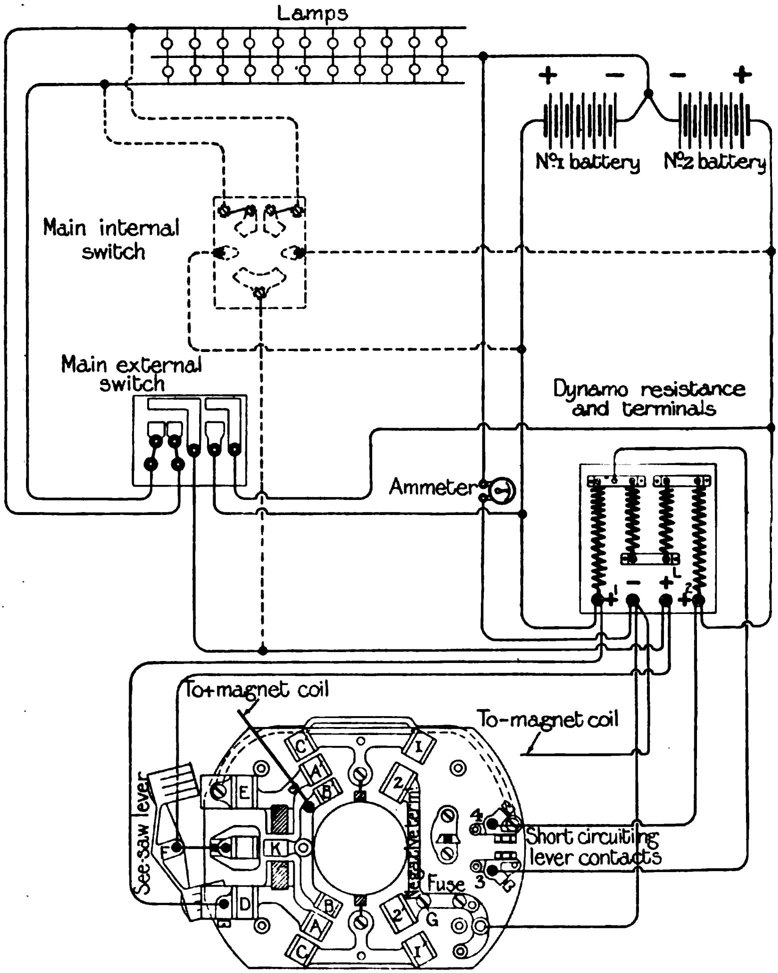

FIG. 3.—Diagram of Connections for "A," "B," "C," "A R," and "C R" Dynamos.

the difference in the voltages between the two batteries. During daylight the main switch is placed horizontal, thus cutting out the resistance and placing both batteries directly across the dynamo terminals. The friction gear for turning the rocking arm is very ingenious. It consists of two plungers, which press lignum vitæ blocks

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on the back end of the rocking arm, which is in the form of a channelled ring. These blocks are pressed on to the ring by springs, gripping it and carrying it round against the stops. As the speed increases the plungers fly out and clear the ring, and thus there is no friction during the higher speeds.

Wiring.—The simplest method of wiring is to run all the wires outside and on the roof, but if side brackets are required, internal wiring must be resorted to. Lead-covered cable attached to small wood blocks is used for roof work, and in some cases is boxed in to further prevent damage from being walked upon. Double switching of lamps is generally used for ordinary coaches, thus necessitating three wires, as shown on Fig. 4.

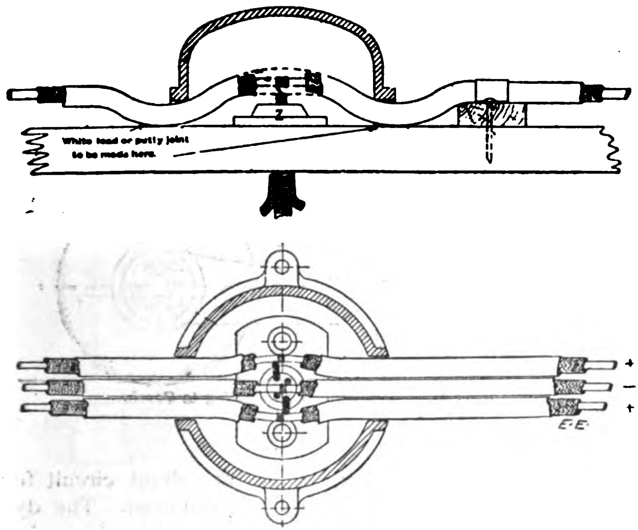

FIG. 4.

The system works quite satisfactorily, and is extensively used on many railways, both in England and abroad.

An ingenious method of testing the specific gravity of the cells has been adopted. An ebonite tube is placed in each accumulator and connected by a rubber tube to a lead nipple which projects outside the box. When required to examine the specific gravity, a small syphon with a rubber tube connection is inserted in the lead nipple, and by squeezing and releasing the rubber ball of the syphon tube the acid rises in the tube containing the hydrometer. Water can also be added by the same apparatus.

VICKERS-HALL SYSTEM.

This system depends entirely upon electrical methods of voltage regulation, and is made for single or double battery working. The

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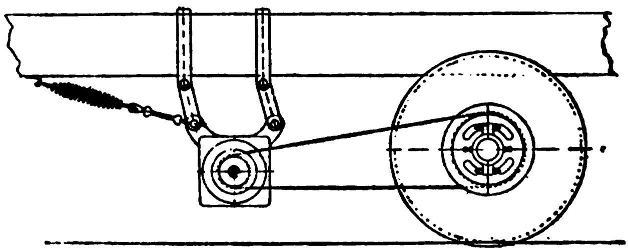
single-battery system is used for small or ordinary compartment coaches where either full or half lights can only be switched on. The dynamo supplies the lamps through resistance, and any excess current passes to the battery. Thus, if individual lighting is required whilst the dynamo is running, the voltage at the lamps cannot be regulated without special means. The double-battery system obviates this difficulty, and is used for such coaches as sleeping and dining carriages, where individual lighting is a necessity. One battery is used to float on the lamps whilst the other is being charged. These batteries are alternately changed each time the dynamo stops, instead of (as in the Stone's system) each time the dynamo is reversed. This, then, allows single lamps to be used with small rise of voltage on the lamps. The voltage generated at the various speeds above the predetermined amount is regulated by using a series winding, wound inversely with the shunt winding, so that the field is weakened as the current increases. Additional regulation is provided by an automatic regulating slide, described later. An external resistance,



Method of attaching to Coach.

FIG. 5.

called an output adjuster, is also fixed in the shunt circuit for the purpose of regulating the maximum current required. The dynamo for both systems is hung as shown in Fig. 5, and is always kept in a horizontal position, thus avoiding any trouble with the ring lubrication. The tension spring keeps the belt tight, and at the same time allows for the motion of the bogie when fitted to such coaches.

Single-Battery System.—The dynamo is four-pole compound-wound as previously mentioned, and carries at one end the automatic regulating gear, as shown on Fig. 6. The pole-changing switch is also carried at the end of this gear, and by its means current is always supplied in the same direction. The regulating mechanism is composed of the following parts: The governor, consisting of a disc, 4, containing two radial slots placed diametrically opposite. In these slots slide two weights, 5, connected by chains passing over rollers to an arrangement called the spring box, 8, which slides along the shaft, and is held away from the governor disc by springs, 7. The spring box is attached to a tube, which slides with it, and forms the cone of a ball bearing, 9. The cups of the ball race are fixed in an aluminium cup, 13,

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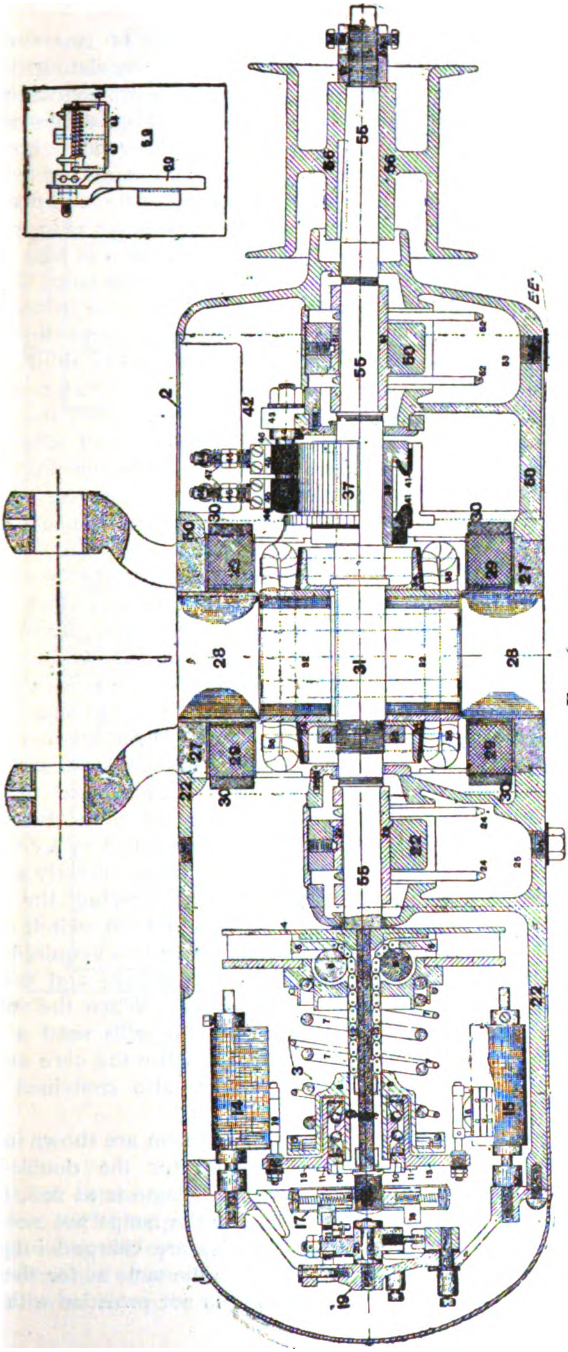

FIG. 6.

having two arms, which carry the brushes, 16, of two resistances, called the lamp and regulating slides. The regulating slide, 14, consists of a number of contacts, part of which are connected to the series winding and the remainder to the shunt regulating resistances. The sliding brush moved by the governor is so designed that, when the dynamo is at rest, both the compound coils and the shunt resistances are short-circuited. As the speed increases, first the compound coils are thrown into circuit, and then the shunt resistance is inserted step by step. By this means the output of the dynamo is kept constant over the whole range of speeds. The lamp resistance, 15, is so connected to the main switch that when the lamps are in use current passes through all the resistance if half lights are on, and through part of it if all lights are on. The resistance is composed of similar units to the regulating slide, so that when the dynamo is at rest all the resistance is short-circuited, but as the speed increases the brush is gradually drawn out, thus cutting in the resistances until, when the full ouput is reached, all the resistance is in circuit. The current is kept in a constant direction in the outside circuit by a change-over switch, 19, consisting of two insulated moving blades and three fixed contacts, the two outer ones being connected together, the whole forming a reversing switch. The blades are connected to the brushes, and the contacts to the external circuits. The switch is forced over one way or the other, according to the direction of rotation, by means of a pole-changer actuator, 17. This consists of a body containing two radial guides, and revolving with the shaft. In the guides slide two weights, 18, controlled by springs, and held near the shaft when at rest. When the dynamo starts they strike a trigger connected to the switch, forcing it into its proper position, and as soon as speed is reached, the weights fly out by centrifugal force, and clear the trigger. An automatic switch or cut-out which controls the connections outside the dynamo is fixed inside the coach. It is controlled by a compound-wound electromagnet, the fine-wire winding being directly across the dynamo terminals, and the series winding carrying the dynamo current. A controlling spring is provided, so that the switch does not close until the dynamo voltage is 6 volts above that required for the lamps. The shunt current now closes the switch, and the series winding reinforces it, and makes a firm contact. When the voltage of the dynamo falls below that of the cells, the cells send a reverse current round the series coil, and so demagnetise the core and open the switch. The main and shunt fuses are also contained in this box.

The connections for the single-battery system are shown in Fig. 7.

Double-Battery System.—The connections for the double-battery system are shown in Fig. 8. When the dynamo is at rest, the two batteries supply the lamps in parallel. If the lamps are not in use when the dynamo is running, the batteries are charged in parallel. The dynamo and regulating mechanism are the same as for the single-battery system, except that the lamp slide is not provided with a half-

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light connection. The principal difference lies in the automatic cut-out, which in this system consists of two electromagnetic switches, and each switch has four contacts, contacts being also made when the switches are down. It will be seen by following the connections that

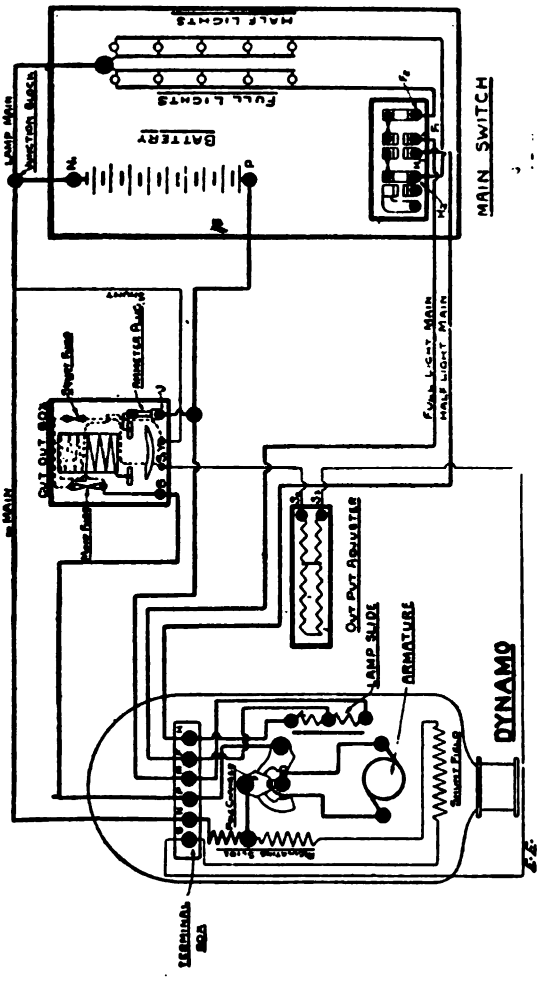

Fig. 7.—Single Battery System—Wiring Diagram.

each cut-out connects its own battery when up to the dynamo, and when down to the lamps, and although both can be down at the same time both cannot be up together. This is prevented by a small change-over switch, fixed at the top of the cut-outs, into the shunt windings of the coils, so as to excite these windings alternately. This switch is

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actuated by means of two ratchet wheels mounted on its axle, the wheels being turned by a pawl mounted on each plunger of the cut-out coils. By this means the switch is moved one step each time the

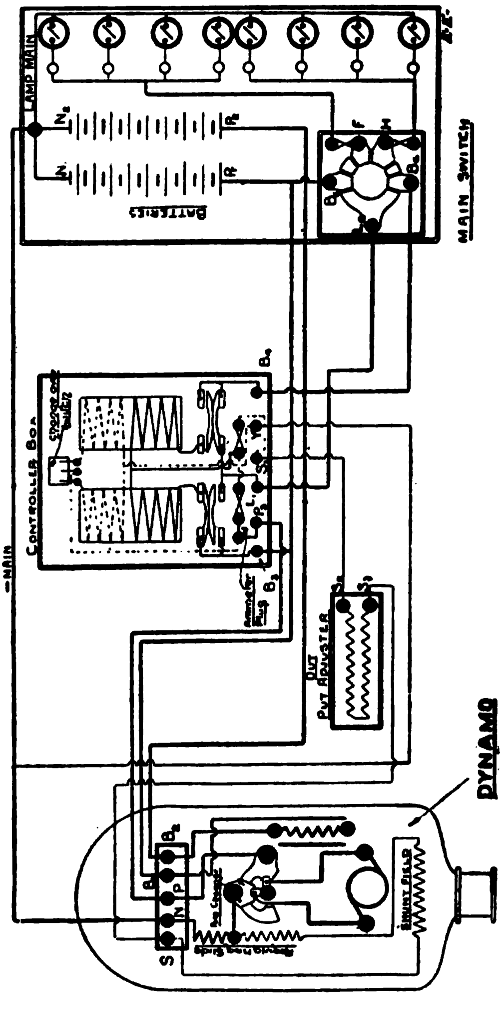

FIG. 8.—Double Battery System—Wiring Diagram.

dynamo stops. The main switch consists of five contacts—three for the lamps and two for connecting the batteries directly in parallel when the lamps are not in use, the switch bridging the lamp resistance.

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Verity-Dalziel System.

This system, which was only brought out towards the end of last year, depends upon electrical regulation of the voltage by auxiliary machines running independently of the dynamo, but driven by the dynamo through a small motor. The dynamo is an ordinary shunt-wound machine fitted with a pole-changing switch to deliver current always in the same direction. An automatic switch, containing two electromagnets and also one battery, complete the special arrangements required for the system. The battery is only necessary for lighting whilst the train is standing, or running at too slow a speed for the dynamo to generate. The regulation of the voltage depends entirely on the auxiliary machines. This machine consists of three small motors, about the size of desk fan motors, the three armatures being built up on one shaft running in two bearings. The connections are shown clearly in Fig. 9, and the three machines are named motor, M, controller, C, and exciter, E, the main dynamo being marked D.

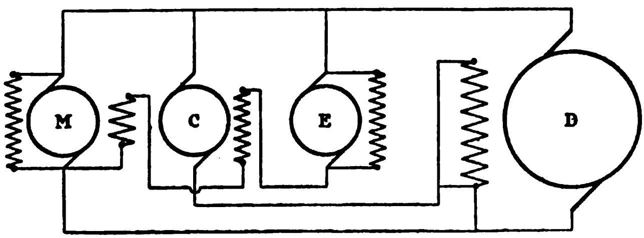

Fig. 9.

Each machine of the regulator has a set of shunt-coils, and the motor has, in addition, a series coil, the current through which does not, however, pass through its own armature, but through that of the exciter. As will be seen from the diagram, the controller armature is permanently connected in series with the main dynamo shunt circuit. The motor armature with its field is directly across the mains. From the positive main, current passes through the exciter armature and field coil to the controller field coil and the motor series field coil. The lamp voltage used is 50, and the normal dynamo voltage is about 58 or 59 volts, and the exciter, which is wound with a highly saturated field, gives about 55 to 56 volts at the lower speeds. Neglecting the pressure drop in the motor series coil, it is clear that the voltage across the controller field will represent the difference between the voltage across the dynamo mains and that of the exciter. The controller armature, therefore, generates voltage in one direction or the other, accordingly as the main voltage is greater or less than the standard, opposing the main voltage in the former and assisting it in the latter case. Thus, if the pressure of the generator rises slightly above that of the standard or exciter pressure, the strength of the dynamo field coil is greatly cut down. In itself, this arrangement, while it definitely

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limits the possible variations of the dynamo pressure to a small amount, does not give quite a constant voltage. By means of the motor series coil, however, as the train speed increases, and consequently, the current to the exciter rises, the motor field strength is also increased, and the speed of the regulating machines is reduced, the voltage of the exciter being, therefore, reduced, so that the controlling effect is increased. In fact, in order to keep the main voltage constant, a little consideration will show that the motor series winding must be so

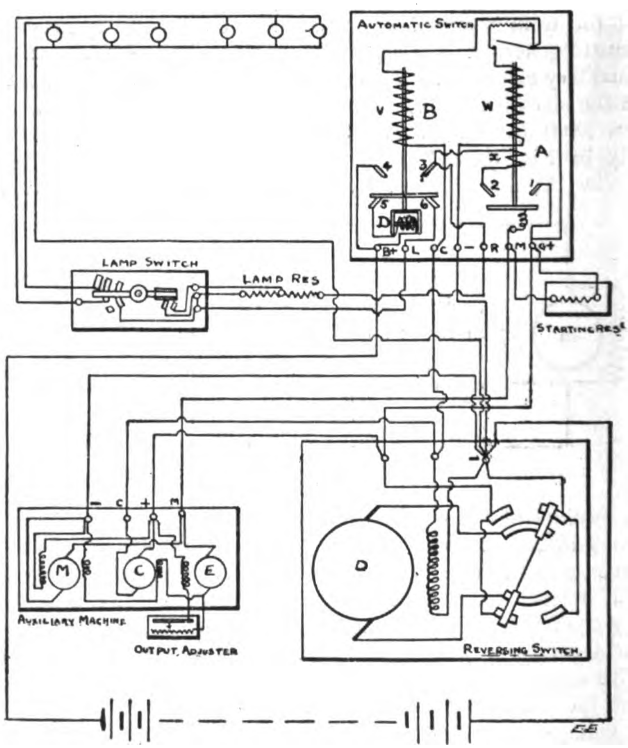

FIG. 10.

proportioned that an increase of voltage on the controller field coils produces an equal decrease in the exciter voltage. The effect is clearly to translate by means of this series winding the increase which would otherwise take place in the main voltage into a decrease of the standard voltage. This series coil can be arranged to give almost any desired effect. From these few facts it will be seen that the system is regulated purely by voltage effects.

Fig. 10 shows the full connections for this system. When the dynamo is not running at sufficient speed, or the coach is standing,

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current is supplied direct from the battery through B+ and coil D on the automatic switch, through 5 and 6 to L, through the lamp switch to lamps and back to the negative of the battery. When the dynamo starts running it excites itself, and current is supplied to the shunt coil, W, of the cut-in switch, A, to the dynamo and auxiliary machine field coils and through the starting resistance of the motor and exciter, raising their speed as the dynamo voltage increases. When the voltage is about 45 volts, the coil A closes the contacts 1 and 2, and at the same time short-circuits the starting resistance. The auxiliary machines now speed up and the exciter rises to full voltage, as previously mentioned, and sends current through the field coils of the controller and the motor series coil. This causes the controller to "boost" up the voltage on the dynamo field winding, and the effect is such that when the switch A cuts in the dynamo voltage rises to 55. The dynamo begins to supply current through coil X to 3 and R, and

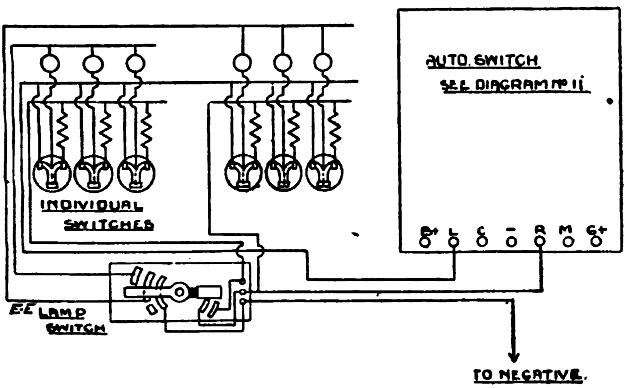

FIG. 11.

through the lamp resistances to the lamp switch and lamps. As the voltage rises more current is supplied to the lamps from the dynamo, which gradually takes over the lamp current until the voltage rises to 57 or 58 volts, when it supplies all the current. From the diagram it will be seen that all current from the battery to the lamps must pass through the magnet coil, D, and so long as this current is flowing through D it holds down the switch B, although the magnet excited by coil V is tending to pull it up, V being connected across the controller armature. When the battery ceases to supply any current, coil D ceases to hold the switch down, and coil V raises the switch, closes contacts 3 and 4, putting the battery directly across the dynamo. As the speed of the train increases the controller ceases to "boost" up, and then reverses and "boosts" down the voltage on the dynamo field winding. As the speed of the train falls the boosting-down voltage on the controller diminishes, and, when it reaches a predetermined value, switch B falls on to contacts 5 and 6, putting the

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battery on to the lamps in parallel with the dynamo. As the latter's voltage falls further the battery supplies a reverse current through coil X, from the lamp switch through the resistances. This neutralises the effect of coil W, and the switch A cuts outs, disconnecting the lamps

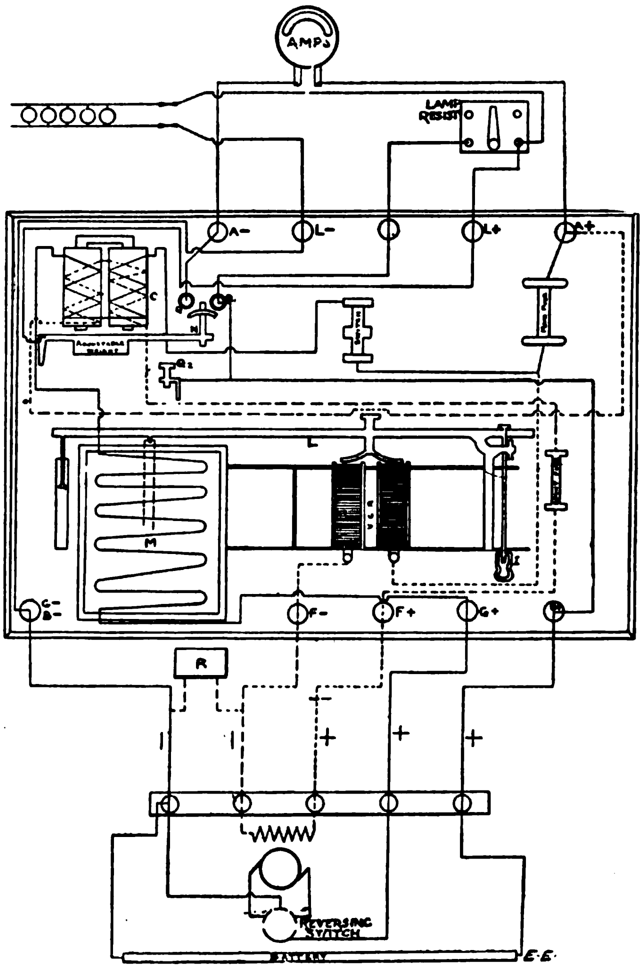

FIG. 12.

from the battery. If by any chance the battery is run completely down, as soon as the switch A cuts in, current goes to the battery through the lamp resistance and the coil D, holding down the switch B until the battery voltage has risen sufficiently.

When individual lighting is required, as in large coaches, a special switching arrangement is used, as shown in Fig. 11. Each switch is

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a three-point switch, and the connections are so arranged with the main switch that when the battery is in use the resistance is disconnected; but when the dynamo is supplying the lamps, the resistance is brought into use with each switch controlling separate lighting points. This system has not yet had any extensive trial.

MOSKOWITZ SYSTEM.

This system depends upon very simple methods of regulation, and is, on the whole, a straightforward system to follow. The method of regulation is electrical, and is entirely carried out by using a variable carbon resistance in parallel with the shunt winding on the dynamo. The dynamo is a shunt-wound machine, with no special arrangements beyond a reversing switch on the end of the shaft for maintaining a constant direction of the current in the external circuits. Fig. 12 shows the complete switching arrangements and connections. The regulating apparatus mentioned above consists of

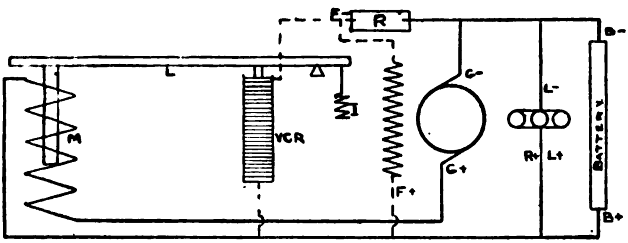

FIG. 13.

a variable carbon plate resistance, V C R, the pressure on the plates being varied by the pull of an electromagnet, M, on a lever, L, and a spring, I, acting against M. This spring can be adjusted to suit any load required. The variable carbon resistance and the shunt winding, which are in parallel, are both in series with a fixed resistance, R, without which the regulation of the field current would be impossible. There is also an automatic cut-out for operating the battery, the coils being in series with the field circuit and also having additional coils in series with the main circuit. This is marked C, and operates a lever switch, N, which closes contacts Q and Q_1, and in the off position makes a contact Q_2. This lever is controlled by an adjustable weight for controlling the voltage at which the dynamo cuts in. There is also a lamp resistance needed, which is in circuit when the dynamo supplies the lamps direct. Fig. 13 shows the principle upon which the regulation is carried out. The system works exceedingly well, and is very simple. One coach in the author's knowledge, ran for 13 months, the lights being in use about four hours per day, and during the whole time only one lamp was changed, showing that the regulation must have been good. Little or no attention beyond oiling was given to the installation.

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Leitner-Lucas System.

This system depends upon electrical methods of voltage regulation, and is made for single-battery working only. The component parts consist of a dynamo, an automatic cut-out, and the battery. A special

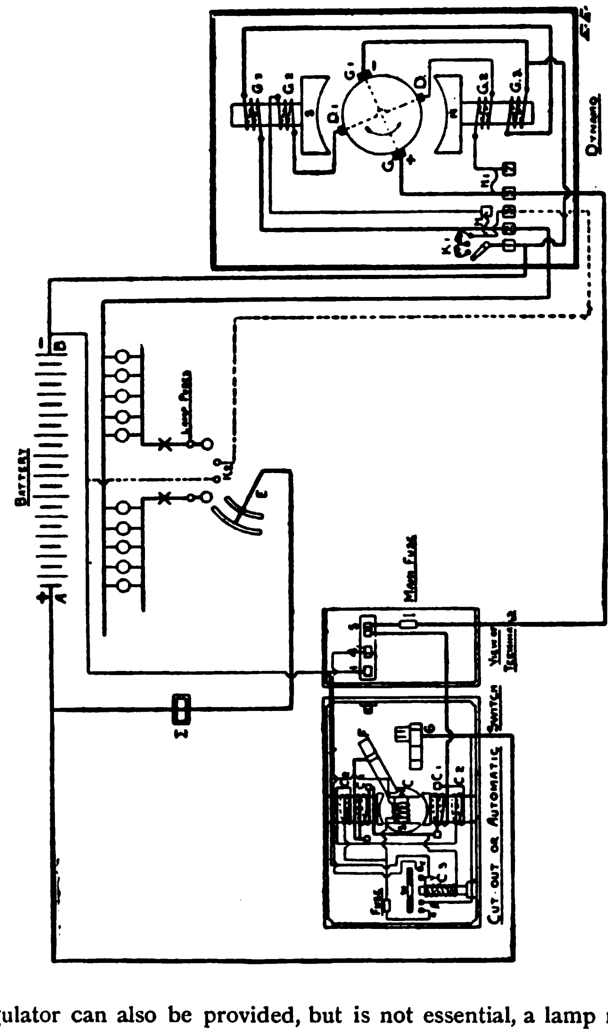

Fig. 14.

regulator can also be provided, but is not essential, a lamp resistance being substituted as much cheaper in first cost. The dynamo is provided with an extra pair of brushes, fixed at right angles to the main brushes, and forming an angle of 20 deg. with the vertical in two-pole machines and 10 deg. in a four-pole machine. Fig. 14 shows

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the simple connections for a two-pole machine. At starting, D_1 is positive and D negative, so that any voltage generated between D and D_1 assists in building up the field. But as the main current increases, the armature flux in the direction of G G_1 increasingly distorts the field flux, and thus the original voltage between D D_1 is gradually reduced to zero and then reversed in sign. The result is that the shunt current decreases, and the voltage is kept a constant quantity. G_3 is also an auxiliary field coil in series with the lamps, and assists the dynamo field winding. The automatic cut-out consists of a pivoted, H, armature, carrying a switch arm which is free to rotate through an angle of 30 deg., such rotation being produced by the attraction of two polar projections. The action is differential, depending

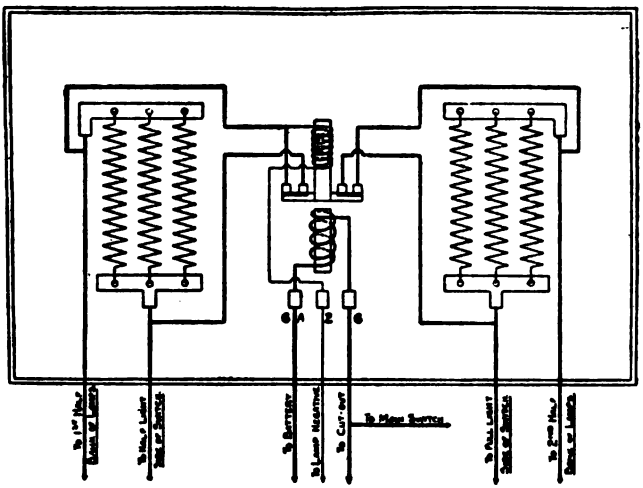

FIG. 15.—Lamp Resistance.

upon the difference in voltage between the dynamo and battery. The lamp resistance is inserted at the points marked ×, and is shown on Fig. 15. It contains a relay switch for the purpose of short-circuiting the resistance when the dynamo is not supplying the lamps. It is operated by two coils, one carrying the charging current to the battery from the dynamo, causing the switch to open. The other is a shunt across the lamps, causing the switch to close. Thus when the lamp switch is put on, and the dynamo is running, the switch will open and the lamp current pass through the resistance. If the dynamo voltage falls, and the switch marked F in Fig. 14 opens, the resistance switch closes and current passes direct from the battery to the lamps.

If accurate regulation is required, a piece of apparatus termed the regulator is substituted for the lamp resistance. Fig. 16 shows

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this regulator with all the connections. It consists of a voltage balance, M, S, Q, and Q_1, M being a solenoid actuating a balanced lever which, moving on a fulcrum, makes contact at Q or Q_1, depending upon whether the pull of M overcomes or is overcome by the spring, S. The positive end of M is at N_3, which is a calibrating resistance in series with M, and which is further in series with a row of resistances, N, to which current from the positive end (from 6, Fig. 14), *viâ* T, is conducted through a revolving arm, W. This revolving arm is geared to a small motor, O and O_1, operated by a relay, P and P_1. Assuming M energised by the dynamo charging the

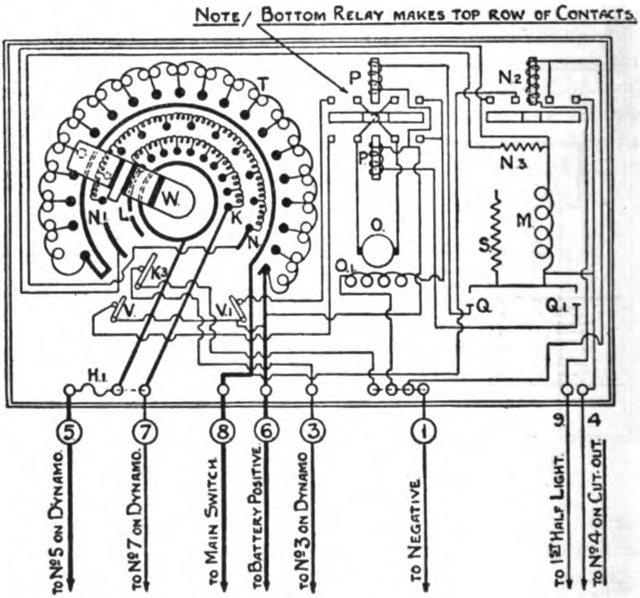

FIG. 16.

batteries, then on a rise of voltage M will overcome S and close Q, energise P, and start the motor, which will rotate W from N. This decreases the current in M so that S pulls off Q, balance is restored, and O stops. As the battery voltage rises, the dynamo voltage rises higher, causing W to move further, until, when three volts per cell are reached, W passes on to N_1, cutting out all resistance in series with M, which closes Q firmly; the motor revolves W until it breaks half the dynamo field at L, and, further on, the other half at K_3; and, finally, the small motor at V. Thus the dynamo runs unloaded, the circuit being broken by the automatic cut-out. In addition to the resistance N, W also cuts in resistance, K, in the field circuits before finally breaking the field. When, now, the lamps

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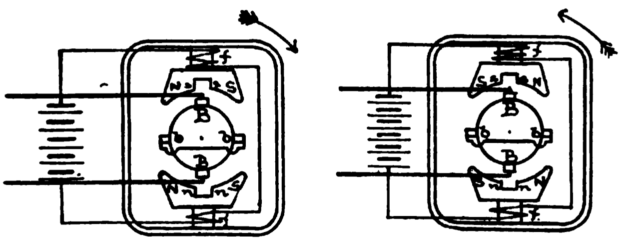
are turned on, the resistances N and N_3 are short-circuited by the relay N_2, putting M in connection with 6 through T. Under these conditions M will balance S at the predetermined voltage to which it is desired to run the lamps, which voltage can be arranged and varied by adjusting S. If the pull of S overcomes M and closes Q_1, the motor is reversed and the arm, W, moves back.

Mather and Platt's System.

This system, which is the invention of Dr. Rosenberg, works upon different principles from any of those previously described. The regulation of the voltage is carried out entirely by the dynamo itself, without any regulating resistances, inverse coils, or auxiliary machinery of any description, and no reversing switch is needed, since the dynamo, due to its special connections, always delivers the current to the circuits in the same direction. The dynamo is two-pole shunt wound with an ordinary armature, but has, in addition to the brushes which supply the current to the circuits, another pair at right angles,



A FIG. 17. B

connected by means of an external conductor, fitted with a fuse. These brushes are shown at B B and *b b* respectively, the latter being short-circuited (Fig. 17). The current through the field windings, *f f*, produces a vertical flux, called the "primary" flux, and indicated by *s s*, *n n*. This produces a difference of potential between *b b* at the neutral points, but none between B B. A current now flows through the armature and between *b* and *b*. This current gives rise to a flux which passes horizontally through the armature. Taking each magnetic flux separately, since the armature revolves in this horizontal flux, a voltage is produced between the brushes B B, and a current, C, is sent into the external circuit. Now this current, C, produces a vertical flux through the armature which opposes the "primary" flux and reduces its magnitude; the current between *b b* is thereby reduced, together with the horizontal flux, and in turn the voltage between B B. This, again, leads to a reduction of the current, C, and, consequently, to a reduction of the vertical armature flux opposed to the primary flux, and so on until a final state of equilibrium is reached. Since the whole action of the dynamo is primarily due to the "primary" flux, *s s*, *n n*,

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it follows that the external current cannot possibly increase beyond a certain value. This limiting value for C is reached when the armature flux between B B is equal in magnitude but opposite in direction to the "primary" flux. This is clear, for the dynamo would at once stop working should the primary flux cease to exist. The limiting value of C is obviously dependent on the strength of the "primary" flux, and thus it is seen that there corresponds a certain external current, C, to every value of field ampere turns. The voltage at the terminals B B is equal to the external current × the external resistance, and this voltage is produced by rotation through the horizontal armature flux due to the short-circuit current. The latter, therefore, is dependent on the speed of the dynamo and the external resistance. Fig. 17 B shows the effect of reversing the direction of rotation: The primary flux remains the same, thus the short-circuit current is reversed; this reverses the horizontal flux, and, therefore, causes the current, C, to flow in the same direction as before. By actual measurement it has been found that at normal speed a short-circuit current equal to about 40 per cent. of the external current, C, is sufficient to set up the required horizontal flux, and in order to produce this short-circuit current the number of ampere turns in coils *f f* have to exceed the number of vertical armature ampere turns by about 10 per cent. only. If, therefore, the speed increases to double the normal, or even to an infinite value, the utmost that can happen is the increase of the external current by something less than 10 per cent., because at this value the "primary" flux is neutralised and the machine would cease working. If the speed falls, the external current will tend to fall, thus increasing the "primary" flux and in turn increasing the horizontal flux just sufficiently to compensate for the drop in speed and leave the external current, C, unchanged.

One of the most important points is, of course, the commutation. The short-circuited brushes are working in the neutral zone. The main brushes, B B, are in the centre of the "primary" flux, but in the neutral zone of the horizontal armature flux. Now, the primary flux is of such an amount as to produce a limited current through the armature and the short-circuited brushes, and the short-circuiting of a few sections by B B does not increase this current. By cutting slots in the pole faces opposite B B the commutation of these brushes takes place in a real neutral zone. The machine has thus been found to run sparklessly in either direction. On the end of the dynamo spindle is a small centrifugal governor of the ordinary type which operates a relay switch, the blades of which work over three contacts, one on the left-hand and two on the right-hand side, insulated from each other. This switch operates the solenoid switch connecting the dynamo to the cells, and *vice versâ*. The solenoid switch is shunt wound only, and is operated by the battery through the relay switch on the dynamo. The core carries switch contacts at the bottom, and also two carbon contacts. This switch closes six contacts, as shown in Fig. 18, which also gives all the connections.

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Conclusions.

After considering the various systems just described, the conclusions arrived at for a successful train-lighting are :—

1. Moving parts must be confined to the armature of the dynamo,

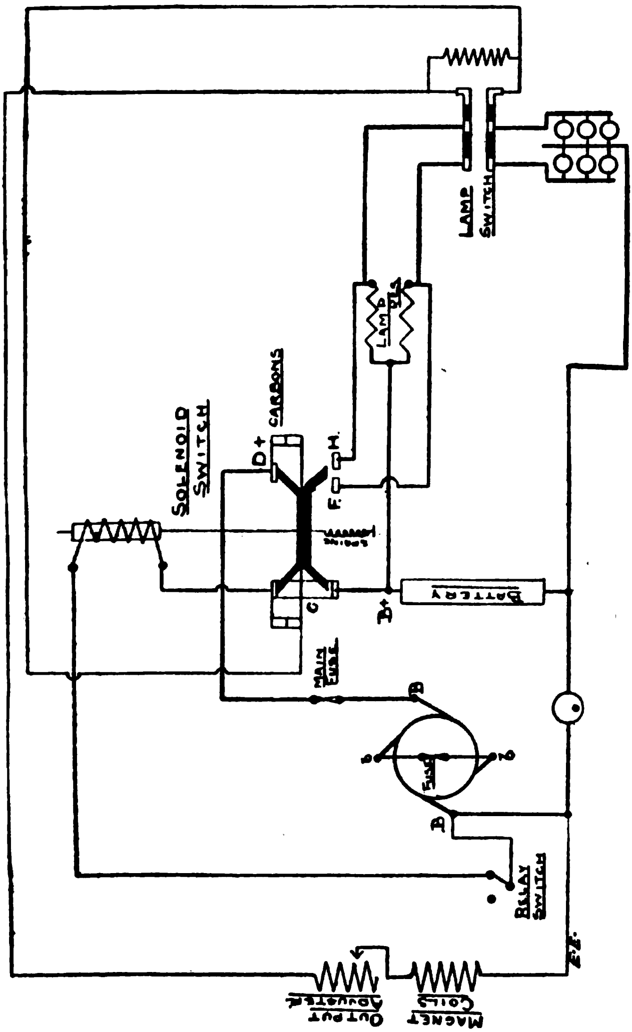

Fig. 18.

one commutator being sufficient to have to keep in order. The addition of motor-driven regulators adds chances of breakdown and increases cost of maintenance, at the same time necessitating complicated connections which would easily baffle an ordinary electrical workman.

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2. The automatic switching of the dynamo should be preferably done by electrical rather than by mechanical methods, although little trouble is experienced with the latter. The magnetic coil of the switch should first be operated by a shunt across the dynamo, or by the field-magnet current. The batteries will then never be connected across the armature of the dynamo if the latter is not generating any voltage.

3. If efficient working of the dynamo is desired the voltage regulation should be done by electrical methods.

4. The use of high efficiency lamps with metallic filaments would be a great saving in power and first costs of all parts, and this part of the business should be looked into, if competition with incandescent gas is to be successful.

5. In bogie coaches the dynamo should be attached to the bogie, thus giving a more uniform wearing of the belt.

The thanks of the author are due to Mr. Pigg and Mr. F. O. Hunt for revising the paper, to Mr. Angus (the lighting inspector for the North-Eastern Railway) for the particulars of gas lighting, and to the various firms mentioned for all particulars placed at his disposal.

Discussion.

Mr. Dalziel.

Mr. J. Dalziel: The author has practically exhausted the subject so far as systems in use in this country are concerned. Every one will agree with his demands for simplicity, but his definition of simplicity of apparatus is open to some question. He takes exception to the presence of more than a single commutator and to multiplicity of connections. Of course, if a simple dynamo and a simple switch would do the job and do it properly, treating the whole apparatus fairly so as to obviate all undue maintenance of any part, and at the same time giving passable regulation without outrageous energy consumption, there is an end to it. The paper makes it clear, however, that regulating devices of some kind are inherent to all systems. Now most engineers would prefer to maintain half a dozen machines with commutators rather than a single set of heavily worked switchgear or a set of mechanical governing apparatus. The tendency in other branches of engineering is all for multiplying the plain motors and dynamos rather than the accessory apparatus, hence the numerous examples we have of multi-motor apparatus. Nothing can give much less trouble, in fact, than the commutators of well and liberally designed machines running under easy conditions and having no abnormal features.

The principle of regulating variable speed dynamos by purely dynamo-electric effects, which is bound up with this question of multiplicity of commutators, would appear to be a very sound one indeed. It is the only principle working on which a designer may set himself down before a set of known quantities, known conditions, and definitely calculable results, and so assure himself of what his

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results are to be from the outset, so as to produce apparatus which requires no trial and error adjustment after manufacture, and the working of which cannot be upset by any unauthorised or mistaken interference. This is a point of great importance. Mr. Dalziel.

As regards connections: The making of these is a matter of elementary wiring, and they do not enter into questions of maintenance. Workmen very quickly get their own ideas—very practical ones usually—of the working of the apparatus they have to deal with.

It will have been noted that with one exception—the third described—all the systems mentioned in the paper regulate by maintaining the *current output* constant. This gives satisfactory results as regards steady *voltage*, provided there be a means whereby a slight rise in voltage gives rise to a proportionately greater rise in current. This means is provided in the battery. Without the battery, itself of approximately constant potential, all such systems would give pressures varying much too widely at different speeds. In other words, the battery, and one might almost say the battery alone, is the real source of regulation in the systems. The voltage then necessarily and actually follows the battery condition closely, and varies considerably between the full charge and full discharge conditions of the latter, hence the double battery of some systems and the automatic regulators of others.

As the current output from the dynamo is invariable, it is fairly clear that the recovery of a badly discharged battery is a somewhat slow process, particularly when lights have to be in use, though in this connection it would appear that a system like Stone's, being "constant torque," and therefore allowing of an increase in current when there is only a low voltage across the dynamo fields, has a slight advantage in this respect over pure constant-current systems, as in the other cases which have all what are practically compound coils inverse to the shunt winding or the equivalent. Further, a train-lighting battery has clearly to stand a large amount of overcharging. The latter is always preferable to undercharging; in fact, it would appear essential to design for this normally so as to ensure satisfactory working on the worst possible service, where lights may be nearly always on. This must result in increased size of generating apparatus, while the battery must itself be large if it is to properly fulfil and withstand for any reasonable length of time its regulating functions as well as provide storage. Coaches in regular service are favourably situated and give good results, as their generating output can be adjusted to the conditions, but if electric train-lighting is to become general, most coaches must be able to run anywhere and do anything indiscriminately.

It is obvious, then, that the batteries come in for some very rough treatment, while they are expensive, and—particularly in double battery systems—large in number. The chief fault to be found with the paper is that it somewhat overlooks this battery maintenance side of the question, for cell maintenance, as a matter of fact, is at present by far the heaviest item of total equipment maintenance. To remedy this

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Mr. Dalziel. state of matters it appears essential to depart entirely from existing methods of regulation. Batteries are frequently charged on constant potential, particularly on the Continent, with satisfactory results, and were this method of working adopted the relief of the battery from its regulating duties and the impressing of a constant potential across it during the running of the generating apparatus would ensure its being maintained always well up to charge, and its very rapid recovery after discharge and over discharge. Its reduction to a single battery of minimum storage capacity and a great reduction in maintenance costs would follow. Incidentally, the coach circuits would be put on the basis of ordinary constant potential circuits, lights could be switched on and off without any effect on the regulation, and the pressure would be rendered altogether independent of battery condition, excepting only during stoppages. Further, not only is the method of working one that as regards driving power absorbed is highly efficient in itself, but as over-charging would be abolished, the power now so lost would also be saved. The third system described is a purely constant voltage working on this principle, and, therefore, embodies a radical departure from the principles previously accepted.

In connection with reduction in battery size, it is sometimes claimed that a large capacity may be of use in enabling a disabled coach to get home. It might, but if train-lighting by electricity is to be successful commercially, the proportion of coaches becoming disabled must be cut down to a less figure than will justify the spending of, say, some £10 to £15 extra per equipment and the hauling about of some 25 to 50 per cent. extra weight on every coach.

An important point mentioned in the paper is that of increasing the pressure from 24 volts. The cables for large coaches, such as diners, become of enormous size at this low pressure, as to avoid dropping a high percentage of this pressure they have to be run at not much more than 300 amps. per square inch or so. They are thus both expensive in themselves and difficult to find accommodation for. I have frequently seen coaches the lights of which very perceptibly shaded off along their length from fairly good to middling and from that to bad. This bears out the point, that wires of section too small to prevent a drop appreciable on such a low voltage have been used, also the main wires of both poles having been mistakenly carried up the same end of the coaches.

Cells though larger in number at higher voltage would be individually less in weight, and this point is of importance, as such cells have to be handled under the coaches in very awkward positions and in minimum time.

Mr. Pigg. Mr. JAMES PIGG: The author has dealt very fully with a subject which is rapidly assuming considerable importance, and one which in the near future will, it is to be hoped, lead to a considerable extension of electrical business.

The paper deals with the subject from the financial, the technical, and the operative point of view, and also refers to the safety of the

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various arrangements in competition for train-lighting. One may not agree altogether with some of the deductions drawn by the author, but in many cases they are very valuable. The financial statements on page 134 are of an important character. Careful examination of these statements shows the large amount allotted to the cost of electric lighting for capital charges, and from this the deduction is obvious that the cost of installation is high. Taking the author's figures as they are given in the paper, it seems that the cost per coach for electric equipment is about £150, and the charge for interest on capital is 55 per cent. of the annual cost of operation. Mr. Pigg.

The cost of the installation of gas with flat-flame burners is apparently about £48, and the charge for interest on capital is 12 per cent. of the annual cost of operation.

The cost of the installation of gas using incandescent burners is apparently about £70, and the charge for interest on capital is 32 per cent. of the annual cost of operation.

Analysing the figures further, it will be found that the large proportion which the capital charge bears in the annual cost of the use of incandescent gas compared with flat-flame burners is due, not entirely to the greater cost of installation, but in a great degree to a tremendous decrease in the consumption of gas.

These figures point conclusively to the necessity for a reduction in the cost of electric installations, if it is desired to bring them into line with the cost of gas lighting.

I am not sure that the estimates as they stand are such as would be accepted commercially. There does not appear to be any provision for depreciation or a sinking fund. If such an account was included for both gas and electric lighting it is probable that some difference would be made in the comparative estimates. There is no means of getting at this from the accounts referring to gas as given in the paper, as the capital charges on the cost of the gas works are not separately shown. As far as can be ascertained, however, the capital charge referred to is only a charge for interest.

There is another charge that some railway companies would be inclined to impose on any electric-lighting scheme put forward to displace existing gas lighting. Such displacement would result, in all probability, in a loss being incurred in disposing of the displaced plant, and one has often, in similar circumstances, to arrange for a payment of interest on unrealisable capital, before any advantage can be claimed for a proposed scheme.

There is one point in connection with the comparative costs which should not be lost sight of, and that is that an electric installation on a coach is a complete manufacturing, distributing and utilising installation. This is not the case with a gas installation. Mr. Henderson's estimates afford no information on this question in connection with gas, and his installation costs are obviously not a complete comparison. No reliable comparison, I think, can be made on estimates of the cost per coach. The only real comparison is the relative actual total cost in each case.

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Mr. Pigg. In this respect the experience of the London and North Western Railway Company with Stone's system of lighting is interesting. Some 1,138 coaches, already fitted with gas, were stripped and lighted electrically at a cost of £88,345, or an average of £77 13s. per coach, which is little more than 50 per cent. of the figure taken by Mr. Henderson.

The cost of the lighting by oil gas, including interest on capital, was £15,150 per annum.

The cost of the electric lighting which displaced the oil gas, including interest on capital, was £9,792 per annum, thus showing a saving of about £6,246 per annum, or about 41 per cent. of the cost of the precious gas installation.

These figures represent: Interest £3 2s., maintenance £5 10s. per coach.

If to this we add the author's estimate of the cost of coal, we get a total of £9 12s. 6d. per coach per annum, which is only about 10 per cent. higher than the author's figures for incandescent gas. If we took the item for maintenance given in the paper (£3 19s. 6d.) instead of £5 10s. as above, the results would be in favour of the electric light. There is no doubt that the figure of £5 10s. per coach per annum for maintenance is very high. Other statistics covering eight half years give figures varying from £5 5s. to £4 8s. per coach per annum.

The organisation of the arrangements for the effective maintenance of train-lighting is not an easy matter, and the number of vehicles in use has a considerable effect upon the cost of maintenance. In the figures last quoted the effects of additions to the electrically lighted stock can be clearly seen in the costs for maintenance. With a given staff there is a maximum number of coaches that can be dealt with, and the cost per coach is a minimum. A further increase of coaches renders an increase of staff necessary, and there is an increase in the cost per coach. Further increases of coaches up to a second maximum again bring down the cost per coach, and so on.

The results obtained by the London, Brighton, and South Coast Railway Company with the Stroudley-Houghton and the Stone's systems are interesting. When the former system, fitted on 380 coaches, was in use alone, the average annual cost for maintenance was £5 19s. 1½d. per coach. Later, when Stone's system had been applied to 293 coaches and the Stroudley-Houghton system was used on 271 other coaches, the annual cost for maintenance was £4 17s. 1½d. per coach, a decrease of 19 per cent.

Sir W. H. Preece's report on train-lighting has been quoted by the author. That report says that the question of the cost of power is not appreciated. Personally, and with all due respect to the authority with which Sir W. H. Preece is entitled to speak, I suggest that Mr. Henderson's statistics show that the question has been somewhat over-appreciated in some quarters. As stated in the paper, it is a subject that it is practically impossible to get at directly. No two trials even over the same route and with the same train and engine can be looked upon as being made under equal conditions, or will give the same results. Some

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time ago one of the railway companies made experiments, and the figures were given as, say, A lbs. per that very elastic unit the train-mile. Later, it was found that the decimal point had been misplaced, and that the true figure was $\frac{A}{10}$ lbs. per train-mile. Such figures are practically useless. A "train" may be of any size within the limits required for traffic. None of the results obtained from the numerous experiments made have obtained general acceptance. In some cases the results would seem to prove that the electric-lighting equipment was helping to propel the train. There is no question, of course, that some extra coal is used, but the quantity is so small compared with that used for traction as to be inappreciable with the methods railway companies adopt for checking the consumption. Most of the railway companies using electricity for train-lighting say they are unable to trace any appreciable increase in the quantity of coal used in this cause. Mr. Pigg.

Railway companies, like other industrial concerns, find, in many cases, that there are some things they must have irrespective of cost, and the electric lighting of steam-driven trains is likely, in view of the recent remarks of the Inspectors of the Board of Trade, to be one of them. Financial comparisons, whilst of great importance, cannot always be allowed to be the deciding factor. Where the safety of the public is concerned, financial considerations (such as are involved in these comparisons) have necessarily to give way. It is not, however, by any means established that gas lighting, even with the reduced consumption claimed for the incandescent burner, is cheaper than the electric light. The cost of such lighting on one railway is over 14 per cent. higher than the figures given by the author. On the South Eastern and Chatham Railway, the Locomotive Engineer states that it had been found to be not only more satisfactory than gas, but more economical.

Mr. F. O. HUNT: To be brief, I will confine my remarks to the last method mentioned in the paper, namely, that invented by Dr. Rosenberg and made by Messrs. Mather and Platt. Mr. Hunt.

Although the method of reasoning in the paper explains the action of the machine up to a certain point, beyond that point the idea of considering the various magnetising forces as if they produced separate and distinct fluxes, is rather a hindrance than a help. It does not make it clear why the machine regulates so sensitively nor why it is possible to avoid disastrous sparking. Consider, however, the fluxes combined, as they really are, and the difficulty is removed. To use existing diagram, Fig. 17 B, I will describe directions as if on a clock face.

The cross-magnetising effect due to the current which circulates *viâ* the brushes *b b* is always, in two-pole machines, 90 deg. in advance of the original flux, and the combination will give rise to a field in the direction V to XI, and with the requisite proportioning of magnetising effects there may be no flux whatever entering or leaving the armature in the quadrants XII to III and VI to IX; if the current

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Mr. Hunt. taken from brushes $b\,b$ were equal to that from B B, there would actually be no current in the conductors lying in those quadrants.

According to the tests quoted in the paper this is not so, but that taken from B B is the greater.

Thus under brushes $b\,b$ no change in the direction of current actually takes place. The current value merely falls, and therefore the condition of sparkless collection is easily met by means of carbon brushes.

With the condition of field we have been considering, the brushes B B are in the position of having a positive lead, and therefore commutation presents no difficulty. The sensitive regulation is also easily accounted for upon the above hypotheses.

The small current in the conductors in the idle quadrants III to XII and IX to VI give rise to a slight back-magnetising force upon the real working field. Consequently a comparatively small increase in the current taken from the brushes B B will give rise to a considerable percentage increase in the back-magnetising force, thus diminishing the working E.M.F. and keeping the rise of current in check.

If the opposite direction of rotation be considered, it will be found that the quadrants IX to XII and III to VI have now become the idle quadrants, so that the whole conditions have adjusted themselves to the changed direction of rotation without any movement of brushes or reversing switches.

This dynamo is thus an automatic regulator to constant current and depends for its constant pressure qualities upon the constancy of the load.

Mr. Henderson. MR. HENDERSON (*in reply*): The whole question of the general adoption of electricity for train-lighting depends upon the relative costs of electricity and gas. Most large railways have complete gas-making plants and apparatus for carriage lighting. The universal clearing out of this plant and its replacement by electric-lighting systems can hardly be expected when, by a small increase of capital cost, a greatly improved light can be obtained by incandescent gas. If the costs given in the paper are examined, it will be seen that so far as electricity is concerned, the interest on capital cost is the largest item, and in order to compete successfully, this point must be looked to by manufacturers. It has been stated that by introducing high-efficiency lamps the light can be greatly increased. Now, I hold that the present light given by the ordinary lamps is ample, and that the capacity of the plant should be decreased rather than the light increased. I have been taken to task by manufacturers for remarking upon the complications of some of the connections, and also for the objections to running machinery beyond that of the dynamo. My point is that a constant voltage can be very simply and satisfactorily obtained, as shown in one of the systems, by purely switch control. If, therefore, this can be done, then surely additional machinery must add complications and also increase capital and maintenance costs. No mention has been made of batteries in the paper, because all

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Mr. Henderson.

engineers will readily understand that, large or small, they will, under the conditions of working, be expensive items, and that system which could dispense with batteries would undoubtedly be the coming one, provided the individuality of the coach could be maintained. If this paper is the means of bringing the subject into more prominence, it will have served a useful purpose, for undoubtedly the general adoption of electric lighting for carriages would mean work for manufacturers for years to come. The great point to be kept in view is the fact that we must reduce the annual charge below that of incandescent gas, and to do this the capital cost must be reduced, and then, if possible, reduce the actual maintenance cost by dispensing with batteries which take up a very large proportion of this cost.

The only reliable method of comparison of costs per coach is to take similar coaches. The question of installation cost per coach in the case of gas, cannot be made to include capital cost of gas works, as this cost per coach must, up to the maximum output of the gas works, be a decreasing quantity as the number of coaches increases. The interest on the capital cost of the works is therefore added to the cost of gas per 1,000 feet.

The cost per coach on the London and North-Western, shown as £77 13s., does not include a complete equipment for each of the coaches, as in a large number of cases each dynamo supplies two coaches, and in some cases three. Another set of costs would therefore be required to make a complete comparison for these trains. The costs given in the paper are taken from actual measurements in the case of the gas-lighted vehicles.

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GLASGOW LOCAL SECTION.

STORES AND COST-KEEPING FOR ELECTRICITY SUPPLY UNDERTAKINGS.

By D. DENHOLM.

(Paper read March 12, 1907.)

INTRODUCTION.

The importance of having a properly organised and efficient system of handling the stores and keeping the costs of electricity supply undertakings is now generally admitted. That this is the case is evident from the general desire for information on the subject, and while it is impossible to devise a system which would apply in all working details to every undertaking, there are certain general arrangements applicable to all. The author hopes that there may be some information in the following paper of interest not only to engineers in charge of electricity supply stations, but to all who have to deal in any way with stores and costing.

In organising a stores and costing system, consideration has to be given to what is required from these departments. The accountant requires that the records must be kept so that he can get the results, and all information as to the working of the whole of the department at any time promptly and accurately.

The engineer's department requires to some extent the same information, but in addition it is stipulated that work must not be delayed owing to any rigid system which will prevent the getting of material promptly and as it is required.

To have a system does not necessarily mean the use of any of the well-known brands of red tape. Red tape must be avoided if the smooth and satisfactory working of any department is to be maintained. That the successful organising and handling of the stores and costing is of the utmost importance, and contributes in no small degree to the success of the undertaking as a whole, can hardly be denied. It is a department which requires the most careful and constant attention, and in the larger undertakings, at any rate, comes perhaps rather more under the control of the engineer's than of the accountant's department.

It is, after all, in the smooth working and successful operation

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from the engineer's point of view that any system of stores and costing must be judged. For this reason, if for no other, engineers would do well to give some attention to this question, and it is submitted that they will find the study of stores and costing work well worth their consideration.

In the electricity department of the city of Glasgow, the work carried on includes everything that can possibly be required in connection with the supply of electricity. In addition to the routine work of the generating stations, and the distribution of supply to consumers, the department employs its own workmen for most of the work in connection with the extensions which are more or less continually going on. This work includes the building of the brickwork settings for new boilers, the foundations for generating sets, work in connection with new sub-stations, the building of ducts for high-tension feeders, the laying of low-tension feeders and distributors, the building of manholes, the erection of section pillars, etc., etc.

There is also a workshop in which section pillar, manhole, and joint box fittings are finished from the casting, movable plant and tools repaired, and a variety of sundry work attended to.

All this involves a corresponding increase and variety in the work of the stores and costing departments, and necessitates a properly organised system if endless confusion is to be avoided.

The stores arrangement described below is based on the system in use in the electricity department of the Glasgow Corporation. The costing arrangement is, however, different, some of the points on which there has been trouble in working being improved upon.

Stores.

General.—In the stores department, a complete and accurate system of requisitioning, purchasing, receiving, storing, distributing, and accounting for all stores is required.

There should be a general store, with a thoroughly experienced storekeeper in charge. At this store all records will be made up, not only for goods received and issued from the store, but for material which is delivered direct on to jobs. At the sub-stations it will not, as a rule, be necessary to keep more than small supplies of running materials, and these materials, issued from the general store, can always be charged direct to the proper job number, as hereafter explained.

The storekeeper would see that the stocks are kept up, goods properly checked and inspected on receipt, and material issued against proper orders. He would be required to keep a keen eye on scrap (a very important item), and generally take an intelligent interest in the work of the department.

If the work of the stores is efficiently carried out, it assists and makes for accuracy in all the work which follows, and of which the storekeeping is the basis.

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Requisitioning of Material.

Requisition Form, No. 1, in duplicate :

First copy to the stores superintendent.
Second copy retained in the book.

Official Order Form, No. 2, in copying ink, and numbered. When the official order has been issued, the requisition, with the official order number and date of issue marked on, is sent to the storekeeper.

Requisition Form, No. 1, would be used :

(*a*) By the storekeeper for stock renewals.
(*b*) By engineers or other responsible persons for requisitioning material which is not regularly stocked.

In some cases two different forms would be used in place of the one form as recommended, but there is no essential reason why the one form should not be sufficient.

On the requisition form would be stated full particulars of the goods required, general allocation number, when wanted, and where the goods are to be delivered.

The stores superintendent, having satisfied himself as to the correctness of all the details on the requisition, issues an official order on the firm which is to supply the goods.

Order Form.—The orders should be typewritten, as pencil orders in duplicate are liable to be more carelessly done and the figures may be mistaken. The typewritten orders should be press-copied into a book, the leaves of which are numbered according to the numbers on the forms. The order should be signed by the chief engineer, or his departmental assistants who have authority to sign for him.

When the official order is issued for the goods, the number of the order and date of issue will be marked on the requisition, which should be sent to the storekeeper.

Filing Requisition Form.—The storekeeper would have it filed on file No. 1, so that when the goods have been delivered he may mark them off on the requisition. The completed requisition would then be filed on file No. 2. The storekeeper has thus two files with requisitions, No. 1 showing all goods on order still to deliver, and file No. 2 with completed requisitions, and showing date of delivery of the goods.

Purchasing.

For goods being supplied under a yearly contract it is simply a matter of clerical routine, but where there is no contract competitive offers should, as a rule, be taken. An Inquiry Form, No. 3, should be used, and unaccepted offers acknowledged and declined on form No. 4.

Specification and Tender Form.—Special attention should be given to the specification and contract form issued for general stores. The

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author has seen some hundreds of these documents, and in very few instances were they properly drawn up. A badly drawn-up specification and form of tender are a sure indication of laxity and inefficiency in other directions. We hear a great deal about organised publicity departments (they are generally called commercial departments) for the purpose of getting consumers on the mains, but any good such a department might do is frequently nullified by the unbusinesslike way in which its ordinary work is carried on. Sending out badly drawn and stupid specifications is only one outward sign of a general inward state.

In drawing up a specification and tender form, foolscap paper of a good quality should be used. On the front page state clearly the general conditions and specification under which the material is to be supplied. On the second page detail the material in the form of a price-list, leaving ample space for filling in prices. In the price-list state as clearly as possible what is required, giving the usual trade description if at all possible. Do not state "best quality, to sample," and then show a third or fourth quality sample. Rather let the offerer send in a sample if there is any doubt as to the quality wanted. On the third page state the letter of offer.

A record of all quotations accepted should be kept on cards or in a loose leaf book.

Invoice prices should be checked against the price which is stated on the order for the goods, and compared with the quotation.

Unaccepted quotations should be filed for reference.

Goods Received.

Goods Received Note, form No. 5, in triplicate books, printed in red:

First copy to accountant.
Second copy to stock clerk.
Third copy retained in the book.

All goods received would be checked on receipt, *i.e.*, weighed and (or) counted as the case might be, and the quantity or weight compared with the supplier's receive note (if one has been received), any difference being noted on the sender's receive note, without, however, altering or erasing the figures thereon.

For all goods received (which includes material returned from jobs, material from workshop, etc., as explained later), a receive note on Goods Received Note, form No. 5, would be made out and signed by the storekeeper, giving full particulars of the goods received, weight or quantity, and remarks as to breakages, shortages, etc., also full particulars of—

(*a*) Packing.
(*b*) Carrier.
(*c*) Whether carriage paid.
(*d*) Amount of carriage.

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These apparently minor details should be carefully given, as they save a great deal of trouble later on, when railway accounts, etc., come to be checked. Goods received notes would be further dealt with as follows :—

(*a*) *Goods received from outside firms.* The first copy, with the sender's receive note, is passed to the accountant. The second copy would be passed to the stock clerk for entry of the material into the stock sheets.

(*b*) *Material returned as unused on the job for which issued* should be entered on a separate receive note, and not along with scrap material. The first copy would be sent to the accountant. The second copy would be passed to the stock clerk, who would make the entries in the stock sheets, and price the items on the receive note. The receive note would then be passed to the cost clerk.

(*c*) *Special allowances for scrap.* Joint boxes, fittings, etc., returned from jobs, which would be worth full value if cleaned up or slightly repaired, and can therefore be used over again, would be treated as scrap on the receive note, but the word "good" in brackets would be written against the item, and due allowance made for same in pricing. This means that such boxes or fittings are debited to "Scrap Account," but when they have been overhauled, a receive note receiving from "Scrap Account" is made out taking them into stock.

(*d*) *Material from the workshop* would be dealt with as in paragraph (*a*).

(*e*) *Material delivered* (*by the supplier*) *direct to a job* on the streets. The foreman in charge of the work would send the supplier's receive note to the stores, and the storekeeper would make out a goods received note for the material, marking it "Delivered direct to ——," *i.e.*, the place where the job is.

(*f*) *Material delivered by the supplier direct to sub-stations.* The engineer in charge would send the supplier's receive note to the stores, and a goods received note would be made out and marked "Delivered direct to ——," giving name of sub-station.

Storing of Goods.

In the design of electricity works the matter of stores accommodation is apt to be somewhat neglected. The author submits that, where the alternatives in the allocation of space at disposal are between, say, a beautiful but practically useless entrance hall and a sufficiency of room for stores, the plea of utility should have preference over the desire for æsthetic effect.

Accommodation required for Stores.—There is one absolutely essential point in stockkeeping, and that is plenty of accommodation for keeping the material properly. It is impossible to keep stock accurately if it is

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all jumbled together and crowded on shelves and bins. There should be ample ranges of shelves, pigeon-holes, drawers, and racks, as well as a margin of floor space.

Labelling of Places containing Stock.—Prominently on the outside of each place containing material there should be a card or a label, form No. 6, fixed, stating: (*a*) Standard List Number; (*b*) Description of Material; (*c*) Minimum Stock; (*d*) Location Number. The standard list number will be found of assistance where the turnover is at all large. In Glasgow, with a stock of something over 10,000 items and an enormous turnover, it was found that confusion arose owing to the same material appearing under two or three different descriptions. To meet this difficulty the stock has been standardised, and every item has a list number, which is used on all orders received, and despatch notes, and other forms. The stock is divided into sections "A" to "Z." The list number consists of the section letter, a numeral, and, where necessary to give a size or a further description, a small alphabetical letter, thus:—

> 1 □" T.C. V.B.S. Callender Cable.
> The section letter is "A."
> The number as per list is "1."

And, as the different makers' cable has to be kept separate, the small letter "*a*" is for the maker's name. The complete list number is, therefore, "A. 1 *a*"; or:—

> 2" Cast Iron Pipes, S. & F.
> The section letter is "B."
> The number as per list is "80."
> The complete list number would be "B. 80."

Again:—

> 4" × $\frac{7}{8}$" H.R.H. Bolts and Nuts, finished.
> The section letter is "L."
> The number for diameter is "38."
> The letter for length is "*k*."
> The complete list number would be "L. 38 *k*."

Minimum Stock.—Where possible the minimum quantity of stock to be held in reserve should be shown on the card, so that as the stores assistant takes material out he may report to the storekeeper immediately the limit is reached.

The location number is the number of the rack, bin, or drawer, as the case may be, and is useful if marked on the stock sheets.

Material should always be put into the stock bins. There should be no bins set aside for workmen or foremen who wish the storekeeper to favour them by keeping the material they are using separate for themselves only. If a certain article or quantity of goods have been ordered for a special job, it may be labelled with these particulars, but so long

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as it is in the store it must be in the stock bin, shelf, or box, as the case may be.

Stock Renewals.—In renewing any article of stock, the old stock must always be used before the new consignment is started upon.

Stocktaking.—Annual stocktaking is always a source of trouble and anxiety, and is apt to be unsatisfactory when done. To avoid this and to secure accuracy in the work, there should be, in addition to the annual stocktaking, a continual checking of the stock against the balances shown on the stock sheets. This can be done by having so many of the items checked weekly by the accountant and the result shown on the stock sheets. When a difference occurs the stock of the item should be taken again within a few weeks, and in this way leakages and errors will be checked and stopped, which, if left to the end of the year, might be lost sight of for lack of time to look into them, or at least would be exceedingly difficult to trace.

The accountant rightly demands that stock shall be accurately kept, much more so now than in days gone by, but this is only possible where a sufficiency of accommodation in the stores renders every item of stock easily and quickly accessible.

Stock Records.

Pricing of Stock Sheets.—It is absolutely necessary that the stock sheets should be carefully and accurately kept. Items should be priced from the invoices, to insure that current prices are always used on despatch notes, etc., and to show the proper value of the stock in hand.

The loose leaf ledger will, in the author's opinion, be found the most convenient form for stock records. Bound books are out of date, and cards have many objectionable features.

Checking of Stock Sheets.—The stock sheets should be checked from the first copy of the goods received note and first copy of the despatch note, which is sent to the accountant.

Distribution of Material.

Goods Despatch Note, form No. 7, in triplicate, printed in black :

First copy to the accountant.
Second copy to the cost office.
Third copy retained in the book.

A despatch note would be made out for all goods sent out from the stores, or for material delivered direct to the jobs or sub-stations.

Material would be supplied against written orders only, the latter made out on the proper form by the foreman or tradesman. The despatches would be dealt with as follows :—

(*a*) For material to tradesmen and others within the department, the first copy of the despatch note, signed by the receiver of the goods and accompanied by the order issued on the store

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(upon which the goods were supplied), would be sent to the accountant. The second copy would be passed to the stores clerk, who would enter the quantities into the stock sheets, price the items on the despatch note, and pass it to the cost clerk.

(*b*) For material delivered direct to jobs on the street, by the supplier, the storekeeper would make out a despatch note (which would be a copy of his receive note made out on receiving the material), marking on it, "Delivered direct by ——," and giving the name of the firm supplying the goods. The copies of the despatch note would be dealt with as in paragraph *a*.

(*c*) For material delivered direct to sub-stations, as in paragraph *b*.

(*d*) For material to the workshop, a despatch note would be made out as in paragraph *a*, except when any box, fitting, or other article is sent for repair or alteration. The order to the workshop on "Order to Workshop," form No. 8, to do the work would be sufficient.

(*e*) For goods sent to persons or firms outside of the department, or for returned empties, etc., despatch notes would be made out as in paragraph *a*, but in addition it is necessary to have an "advice form" to be sent with the goods, or posted to the firm, advising the despatch. Form No. 9 would be suitable.

(*f*) When material out of stock is to be scrapped, a despatch note would be made out as in paragraph *a*. No material would be scrapped out of stock without the authority in writing of the departmental engineer and the stores superintendent.

(*g*) A separate stock account would be kept for all movable plant and tools. A monthly return of tools, etc., condemned as useless would be made up and a despatch note made out for them, debiting to scrap account.

Removal of Ashes, Cartage, etc.

These are matters which are dealt with in different ways according to circumstances. The forms shown, Nos. 10, 11, and 12, may be of interest, and explain themselves.

Costing.

The costing comes under two general headings :—

(*a*) Generating Department.
(*b*) Mains Department.

The generating department costs should include all the work done at the generating stations and sub-stations, as well as the purely generating costs. The mains department costs include all the work of the mains department.

If the job numbers are properly stated by the engineers and fore-

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men in giving their instructions to workmen to begin with, and the work in the stores department is efficiently carried out, the getting out of the costs is much simplified. The cost returns should be made up monthly, and the completed summaries should be in the hands of the chief engineer and his responsible assistants promptly and without delay. These summaries should not be loaded up with details of material and time. They should be concise, clear statements of the work done and the cost of doing it.

Stations and other capital items would be designated by numbers, as follows :—

1\. ... ... Generating Station.
2\. ... ... Generating Station.
3\.
4\. ... ... Sub-Station.
5\. ... ... Sub-Station.
6\. ... ... Sub-Station.
7\. ... ... Sub-Station
8
9\.
10\.
11\. Mains, Feeders, etc.
12\. Meters and Indicators.
13\. Electrical Instruments.
14\. Counting-house Furniture.
15\. General Stock.

The subdivisions of the capital items of the stations would be numbered as follows :—

21\. Lands and Buildings.
22\. Machinery and Plant.
23\. Accumulators.

Revenue items would be numbered as follows :—

41\. Coal.
42\. Carting Ashes.
43\. Oil, Waste, Water, and Engine-room Stores.
44\. Salaries of Superintendents at Generating Stations.
45\. Wages at Generating Stations.
46\. Repairs to Lands and Buildings.
47\. Repairs to Machinery and Plant.
48\. Repairs to Accumulators.
49\. Energy Purchased.

61\. Repairs to Mains, Feeders, etc.
62\. Repairs to Meters and Indicators.
63\. Salaries of Surveyors.

71\. Salaries of Engineer's Department.
72\. Salaries of Accountant's Department.

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73. General Establishment Charges.
74. Stationery, Printing, Advertising, etc.

81. Rents and Feu Duties.
82. Rents, Taxes, and Assessments.
83. Repairs to Public Arc Lamps.
84. Repairs to Private and Public Stair Lighting.
85. Special Charges.

The subdivision of Capital Account No. 12 would be :—

100. New Meters.
101. New Indicators.
102. New Time Switches.
103. Work Chargeable to other sections of the Electricity Department.
104. Laboratory, New Plant, Instruments, and Tools.

The subdivision of Capital Account No. 11 would be :—

300. Branches.
301. Distributors.
302. Arc Distributors.
303. Feeders (Low Tension).
304. Feeders (Extra High Tension).
305. Feeder Manholes (Low Tension).
306. Feeder Manholes (Extra High Tension).
307. Network Manholes.
308. Movable Plant and Tools.
309. Workshop Fixed Plant and Tools.
310. Private Street and Stair Lighting.
311. Telephones.
312. Work Chargeable.

The Revenue Account No. 61 would be subdivided thus :—

400. Branches.
401. Distributors.
402. Arc Distributors.
403. Feeders (Low Tension).
404. Feeders (Extra High Tension).
405. Feeder Manholes (Low Tension).
406. Feeder Manholes (Extra High Tension).
407. Network Manholes.
408. Movable Plant and Tools.
409. Workshop Fixed Plant and Tools.
410. Private Street and Stair Lighting.
411. Telephones.
412. Public Arc Lamps (attending and repairing).

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Revenue Account No. 62 would be subdivided thus :—

200. Repairs to Meters and Indicators.
201. Attending to Complaints.
202. Experimental Work.
203. Changing Meters and Indicators.
204. Repairs to Laboratory Plant, Instruments, and Tools.
205. Repairs to Laboratory Workshops and Offices.

Capital and Revenue Number not used twice.—It will thus be seen that the numbers applicable to capital and to revenue are never used twice, so that there is no difficulty in discriminating as to the number denoting what is chargeable to capital and what is chargeable to revenue. The figures given are those designating the principal accounts to which the cost would be charged in the accountant's books, but the actual cost of a job or piece of work would be specially shown by :—

(A) *In the Case of the Generating Department.*

A running cost number, fixed by the cost clerk, and placed under the principal number already given, thus :—

1 = ... Generating Station.
21 = Lands and Buildings—

and stated 1 × 21, would be the allocation number for work chargeable to capital account done on lands and buildings at —— generating station. If the cost of a particular piece of work is required, a running cost number would be placed under the principal number, thus: $\frac{1 \times 21}{\text{R.C.N.}}$, and all time sheets, order forms for material, etc., would bear that number.

If it should be chargeable to revenue account, the principal number would be $\frac{1 \times 46}{\text{R.C.N.}}$.

(B) *In the Case of the Mains Department.*

A running cost number, fixed by the cost clerk, would be placed under the principal number and district letter thus: An instruction form would be issued to lay a distributor in district "X." The subdivision number for distributors under capital account is 301 ; therefore the job number would be $\frac{\text{X. } 301}{\text{R.C.N.}}$.

If it was maintenance work on a distributor chargeable to revenue account, the principal number would be 401, the whole number being $\frac{\text{X. } 401}{\text{R.C.N.}}$.

Generating Department Engineers and Foremen Order from Stores.—In the generating department it would not, as a rule, be necessary to issue written instructions to workmen for work to be done. The

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engineers and foremen only would order material from the stores, on "Order to Stores," form No. 13. (This form would also be used by workmen under section "B," as explained later. No material would be supplied to a job without an order made out on the proper form, and with the job number stated thereon.)

Mains Department Instruction Form.—In the mains department the work is of a different nature. Jointers, branchmen, etc., are working over large areas, and it is better that each tradesman should have his instructions in writing.

Instructions to Workmen, form No. 14, books in triplicate:

First two copies sent to the cost clerk, who hands the first copy to the workman.
Third copy retained in the book.

The superintendent would issue an instruction form (filling in the workman's name) to do the work, marking thereon the general allocation number, the running cost number being fixed by the cost clerk. This complete number would be used on all subsequent forms issued for work to be done on the same job. The first and second copies of the instruction form would be passed to the cost clerk, who would at once fix the running cost number and hand the first copy to the workman when he reports himself at the time office for starting on his job.

On the back of the form the workman would mark the time spent on the job, and give a note of the material he had used. This list of material would be compared with the amount he had drawn from the stores for the job, as shown by the despatch notes. Any serious difference would be inquired into and reported to the superintendent in charge.

In the case of a large amount of work being carried out to one instruction, the workman would make a weekly return of time and material on a special sheet supplied by the cost clerk, his instruction form being retained until the completion of the job. From the second copy the full particulars of the place and job would be entered into the "instruction form register."

Job Number Register.—In this register would be recorded all the job numbers fixed for work done under section "A."

It is of the utmost importance that this book should be kept up to date and carefully indexed.

Instruction Form Register.—This is the job number book under section "B." The size of book or books required depends on the amount of work being done. The important point is that the book or books must be cross-indexed, and be carefully kept.

Indexing is a matter which it is supposed any one can do. Unfortunately this is not so. Indexing, if it is to be satisfactory, must be intelligently done.

Binding Receive and Despatch Notes.—As already explained, the second copy of the goods received and the goods despatch notes

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are passed to the cost clerk, after having been priced in the stores and had the job numbers stated on them. These notes are now bound into loose binders or files, one binder or file being used for each general allocation number.

From the binders the notes for each running cost number—that is, for each job—are taken and pinned together with—

Sheet for labour.
Sheet for cartage.
Abstract sheet.

Abstract Sheet.—On the abstract sheet would be shown the amount of each class of material used and the totals of the items for cartage and labour.

From the abstract sheets the monthly summaries would be made up and copies supplied to the chief engineer and to all the engineers responsible for the work carried out. Should details of any particular job be required, they would be quickly got at from the bound notes, which would be pigeon-holed and kept for, say, two years.

"*Order to Stores,*" *Form No. 13.*—Each workman working under section "B" arrangements would have an "order to stores" book.

Abstract and summary forms are not shown, as they are simply sheets ruled off to suit individual cases.

In the foregoing paper the author is fully aware that he has by no means exhausted the subject. The handling of the fuel supplies and the time-keeping arrangements have not been touched upon, and much remains to be said of the filing of prices and records, the care of movable plant and tools, the economic handling of scrap, etc. The aim of the paper is not so much to put before this local section any cut-and-dried system as to call the attention of the members to the need for some kind of system if the electrical supply undertakings are to be built up on those sound commercial principles which have been found so indispensable in the commercial development of other great industries.

It is submitted that readily intelligible methods and some definite system with the minimum of complexity are absolutely necessary not only for the proper working of the gigantic undertakings, but for the success of the smallest and most modest concern.

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ELECTRICITY DEPARTMENT.

No. 362

REQUISITION FOR MATERIAL.

Name of Supplier.. ....190 .

Official Order No...

The following is now required:— *Date of Order* ....

STOCK.	LIST NO.	DESCRIPTION.	PRICE.

Deliver at ....

For.. *Signature* ....

FORM NO. I.

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Order No. 6999

TELEGRAMS " "
TELEPHONE .

All Communications to be addressed to the Chief Engineer.

Electricity Department,

....

ORDER.

Please supply the following goods, carriage paid, as per..

	LIST NUMBER.	ALLOCATION NUMBER.

The goods are to be delivered ....
at ....
and must be accompanied by a Receive Note.

Whether the order is for goods to be supplied or for work to be done, TWO PRICED INVOICES, quoting above "Order Number" must be sent to Head Office..*at once, but the Allocation Number is not to be quoted.*

....*Chief Engineer.*

FORM NO. 2.

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....*Electricity Department,*

....

....

Date.. ......

To ....

....

....

QUOTATION WANTED.

Please let me have your price for supplying the undernoted material to this Department :—

Delivery at :—

Terms.—Cash end of month following delivery.

....*Chief Engineer.*

FORM NO. 3.

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ELECTRICITY DEPARTMENT.

....

....190 .

Dear Sir,

Referring to your Quotation of ....

for ....

I have to inform you that a more favourable offer has been accepted, and to thank you for your attention in this matter.

....*Chief Engineer.*

FORM No. 4.

DESCRIPTION.

Date.. *Quantity* ....

List No... *Min. Stock*...

Supplier ....

FORM No. 6.

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ELECTRICITY DEPARTMENT.

Date.. **No. 2797**

ORDER NO.	JOB NO.

RECEIVE NOTE.

Store—

From.. ....*Storekeeper.*

	LIST NO.	MATERIAL.	QUANTITY.					RATE.	£	s.	d.	FOLIO.
			No.	Tons.	Cwts.	Qrs.	Lbs.					

FORM NO. 5.

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ELECTRICITY DEPARTMENT.

Date.. **No. 6797**

DESPATCH NOTE.

ORDER NO.	JOB NO.

Stores—

To..

....*Storekeeper.*

	LIST No.	MATERIAL.	QUANTITY.					RATE.	£	s.	d.	FOLIO.
			No.	TONS.	CWTS.	QRS.	LBS.					

NOTE.—Please sign and return to above store within Two Days from Date. *Received by*..

FORM NO. 7.

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ELECTRICITY DEPARTMENT.

ORDER TO WORKSHOP.

Date..190 .

Job No.......................................

Ordered by..

N.B.—The second copy of this Order is to be sent to the Storekeeper.

FORM No. 8.

ELECTRICITY DEPARTMENT.

No...................

....

To..

....190 .

Please receive the undernoted :—

Signature...

FORM No. 9.

ELECTRICITY DEPARTMENT.

No..............................

REOEIVE ONE OART RUBBISH.

This Ticket, along with the Account, made out against the Electricity Department, to be sent to the Head Office,........................ ....*at the end of each month.*

FORM No. 10.

ELECTRICITY DEPARTMENT.

Cartage of Ashes, etc., from Generating Department.

REOEIVE ONE OART RUBBISH.

Two copies of Account to be sent to Head Office, ...*at the end of each month, along with this Ticket.*

Initialled...

Job No. I × 42.

FORM No. 11.

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ELECTRICITY DEPARTMENT.

No............

CARTING TICKET.

Date..

Contractors ....

Please send...

....

JOB NO.	ORDERED BY.

FORM NO. 12.

ELECTRICITY DEPARTMENT.

No............

....190 .

To Electricity Stores at..

Please supply the undernoted for Job No..................

Ordered by..

N.B.—If the Job No. is not entered above, the Storekeeper will not supply material.

This order applies to Stores Department only, and should any outside firm supply goods on this order form, the account will not be recognised nor paid by the Corporation.

FORM NO. 13.

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ELECTRICITY DEPARTMENT.

No..............

INSTRUOTION FORM.

Workman's Name .... *Job No*.............. *Date*..

Name.. *Address*...

Instructions :—

Instructed by..

FORM NO. 14, FRONT.

TIME AND MATERIAL.

NAME.	TIME.	OVERTIME.

Material used :—

Material returned :—

Signature..

FORM NO. 14, BACK.

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GLASGOW LOCAL SECTION.

THE PAY SHEET.

By R. B. Maccall.

(*Paper read March* 12, 1907.)

The paper which it was intimated that I should read to the Glasgow Section of the Institution of Electrical Engineers on the "Valuation of Electrical Undertakings for the Purposes of Taxation" was duly written, but, as the Corporation may shortly be in the law courts in connection with this question, I deemed it inadvisable at present to discuss the question, and after coming to this decision, as time was limited, I could only write, and have now the honour to lay before you, a short paper on "The Pay Sheet," being notes on the method of making up the pay sheet of the Glasgow Corporation Electricity Department, and on the method of allocating the time and pay of employees entered therein for costing, ledger, and balance-sheet purposes.

In connection with the preparation of the pay sheet there is also brought to your notice the application of the "Addressograph," a machine hitherto used for the purpose of addressing envelopes or wrappers. This machine has been further improved, and we now use it for printing the pay sheet, and also the little envelopes or pay pockets for containing the employees' pays, with the number and name of the employee, and the date of pay printed thereon. Any of the audience who may care to inspect the machine is cordially invited to do so, as two of these machines have been brought to this meeting.

In the preparation of a pay sheet the primary purpose, of course, is that the employee may be paid his proper wage : the second point to get at is the allocation of the time and relative cost upon the jobs on which each employee is engaged, so that the proper accounts may be debited.

Before entering on the first point, I may state that the accounts of the Electricity Department are divided into 27 principal accounts and 24 subsidiary accounts. For the general information of officials and others interested, these accounts have been listed and printed, with a note of the numbers used for allocation purposes. A portion of this information sheet showing the Generating Section Accounts (Form A) is printed on the following page.

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GLASGOW CORPORATION ELECTRICITY DEPARTMENT.

Undernoted are given the principal Allocation Marks which are to be placed on all Orders, Notes for Time or Material expended or to be expended on any Job. In Costing where a Running Cost Number is used, in order to ascertain the cost of a particular Job, the principal Allocation Marks to be placed over the R.C.N. in the manner shown.

GENERATING SECTION.

Work done by the Generating Section workmen on account of the Generating Section is chargeable to one or other of the undernoted accounts. Where work is done by the Generating Section for the Mains Section, then the Mains Section Job Numbers as noted on the other side must be used.

CAPITAL ACCOUNTS.

	Port Dundas.	Pollokshaws Road.	Waterloo Street.	Kelvinside.	John Street.	Byres Road.	Springburn.	French Street.	Cathedral Street.
Land and Buildings	$\frac{1 \times 21}{\text{R.C.N.}}$	$\frac{2 \times 21}{\text{R.C.N.}}$	$\frac{3 \times 21}{\text{R.C.N.}}$	$\frac{4 \times 21}{\text{R.C.N.}}$	$\frac{5 \times 21}{\text{R.C.N.}}$	$\frac{6 \times 21}{\text{R.C.N.}}$	$\frac{7 \times 21}{\text{R.C.N.}}$	$\frac{8 \times 21}{\text{R.C.N.}}$	$\frac{9 \times 21}{\text{R.C.N.}}$
Machinery and Plant	$\frac{1 \times 22}{\text{R.C.N.}}$	$\frac{2 \times 22}{\text{R.C.N.}}$	$\frac{3 \times 22}{\text{R.C.N.}}$	$\frac{4 \times 22}{\text{R.C.N.}}$	$\frac{5 \times 22}{\text{R.C.N.}}$	$\frac{6 \times 22}{\text{R.C.N.}}$	$\frac{7 \times 22}{\text{R.C.N.}}$	$\frac{8 \times 22}{\text{R.C.N.}}$	$\frac{9 \times 22}{\text{R.C.N.}}$
Accumulators	$\frac{1 \times 23}{\text{R.C.N.}}$	$\frac{2 \times 23}{\text{R.C.N.}}$	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.
Electrical Instruments	$\frac{1 \times 13}{\text{R.C.N.}}$	$\frac{2 \times 13}{\text{R.C.N.}}$	$\frac{3 \times 13}{\text{R.C.N.}}$	$\frac{4 \times 13}{\text{R.C.N.}}$	$\frac{5 \times 13}{\text{R.C.N.}}$	$\frac{6 \times 13}{\text{R.C.N.}}$	$\frac{7 \times 13}{\text{R.C.N.}}$	$\frac{8 \times 13}{\text{R.C.N.}}$	$\frac{9 \times 13}{\text{R.C.N.}}$
Counting House Furniture	$\frac{1 \times 14}{\text{R.C.N.}}$	$\frac{2 \times 14}{\text{R.C.N.}}$	$\frac{3 \times 14}{\text{R.C.N.}}$	$\frac{4 \times 14}{\text{R.C.N.}}$	$\frac{5 \times 14}{\text{R.C.N.}}$	$\frac{6 \times 14}{\text{R.C.N.}}$	$\frac{7 \times 14}{\text{R.C.N.}}$	$\frac{8 \times 14}{\text{R.C.N.}}$	$\frac{9 \times 14}{\text{R.C.N.}}$

REVENUE ACCOUNTS.

	Port Dundas.	Pollokshaws Road.	Waterloo Street.	Kelvinside.	John Street.	Byres Road.	Springburn.	French Street.	Cathedral Street.
Coal	1 × 41	2 × 41	Nil.	4 × 41	Nil.	Nil.	Nil.	Nil.	Nil.
Cartage of Ashes, Rubbish, etc.	1 × 42	2 × 42	Nil.	4 × 42	Nil.	Nil.	Nil.	Nil.	Nil.
Oil, Water, Waste and Engine Room Stores ...	$\frac{1 \times 43}{\text{R.C.N.}}$	$\frac{2 \times 43}{\text{R.C.N.}}$	$\frac{3 \times 43}{\text{R.C.N.}}$	$\frac{4 \times 43}{\text{R.C.N.}}$	$\frac{5 \times 43}{\text{R.C.N.}}$	$\frac{6 \times 43}{\text{R.C.N.}}$	$\frac{7 \times 43}{\text{R.C.N.}}$	$\frac{8 \times 43}{\text{R.C.N.}}$	$\frac{9 \times 43}{\text{R.C.N.}}$
Salaries of Superintendents at Stations	1 × 44	2 × 44	3 × 44	4 × 44	5 × 44	6 × 44	7 × 44	8 × 44	9 × 44
Wages at Generation Stations	$\frac{1 \times 45}{\text{R.C.N.}}$	$\frac{2 \times 45}{\text{R.C.N.}}$	$\frac{3 \times 45}{\text{R.C.N.}}$	$\frac{4 \times 45}{\text{R.C.N.}}$	$\frac{5 \times 45}{\text{R.C.N.}}$	$\frac{6 \times 45}{\text{R.C.N.}}$	$\frac{7 \times 45}{\text{R.C.N.}}$	$\frac{8 \times 45}{\text{R.C.N.}}$	$\frac{9 \times 45}{\text{R.C.N.}}$
Repairs to Buildings	$\frac{1 \times 46}{\text{R.C.N.}}$	$\frac{2 \times 46}{\text{R.C.N.}}$	$\frac{3 \times 46}{\text{R.C.N.}}$	$\frac{4 \times 46}{\text{R.C.N.}}$	$\frac{5 \times 46}{\text{R.C.N.}}$	$\frac{6 \times 46}{\text{R.C.N.}}$	$\frac{7 \times 46}{\text{R.C.N.}}$	$\frac{8 \times 46}{\text{R.C.N.}}$	$\frac{9 \times 46}{\text{R.C.N.}}$
Repairs to Machinery and Plant	$\frac{1 \times 47}{\text{R.C.N.}}$	$\frac{2 \times 47}{\text{R.C.N.}}$	$\frac{3 \times 47}{\text{R.C.N.}}$	$\frac{4 \times 47}{\text{R.C.N.}}$	$\frac{5 \times 47}{\text{R.C.N.}}$	$\frac{6 \times 47}{\text{R.C.N.}}$	$\frac{7 \times 47}{\text{R.C.N.}}$	$\frac{8 \times 47}{\text{R.C.N.}}$	$\frac{9 \times 47}{\text{R.C.N.}}$
Repairs to Accumulators	$\frac{1 \times 48}{\text{R.C.N.}}$	$\frac{2 \times 48}{\text{R.C.N.}}$	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.
Energy from Tramways Department	Nil.	2 × 49	3 × 49	Nil.	Nil.	Nil.	7 × 49	8 × 49	Nil.

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These accounts are designated by fixed numbers, thus—

1	signifies	Port Dundas Station.
2	"	Pollokshaws Road Station.
21	"	Land and Buildings.
22	"	Plant and Machinery.

—and so on, and taking the two numbers in conjunction—

Port Dundas Station .	1×21	signifies	Land and Buildings.
Pollokshaws Road Station	2×21	"	" " "
Port Dundas Station .	1×22	"	Plant and Machinery.
Pollokshaws Road Station	2×22	"	" " "

It is evident that any time charged to these accounts does not give the time spent upon any particular job included under these headings, hence a running cost number is used in addition to the principal allocation numbers noted above, such as $\frac{1 \times 22}{150}$ = erecting high tension switchboard, Port Dundas Station. In the generating stations these running cost numbers are given by the station engineer, and in the mains department by the district superintendents. The number thus fixed is given on the workman's instruction order, against which he notes his time in the daily time sheet (Form B). Before this present system of allocation marks came into use, daily time tickets coloured white, blue, and red were in use, for facilitating the costing, and, although under the present system the colour may not be of so much importance, it has been found useful and is retained. White signifies new work or capital expenditure; blue, generation or maintenance costs, *i.e.*, items chargeable to revenue account; and the red signifies the fuel or boiler house work. In the mains section there is only one colour of time ticket used, upon which the men note all the particulars of the time spent upon the various jobs, whether they are capital or revenue.

For facility in paying wages the employees of the department are divided into two sections: one consisting of the men employed in the generating stations, meter workshop, and general offices staff, whose pay week commences on Wednesday morning and finishes on Tuesday evening; and the other section contains the names of those employed in the mains department, whose pay week commences on Thursday morning and finishes on Wednesday evening.

The employees entered in the generating pay list, being mostly employed within doors in the stations or other buildings, hand in their time tickets (Forms B 1, 2 and 3) on leaving off work to the timekeeper at the gate, but the employees of the mains department, being mostly employed out-of-doors, have their tickets (Form B 4) collected by timekeepers.

In the time tickets it will be noted that the time and the overtime are shown separately, and a line for certification by the official who

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....Station. Date..

NEW WORK.	NAME.	NO.	JOB NO.	TIME.	OVERTIME.

Certified by...

FORM B 1, 2, 3.

CORPORATION OF GLASGOW—ELECTRICITY DEPARTMENT.

DAILY TIME TIOKET.

Date...

Workman's Name.................................. ....

No..............................

WHERE WORKING.	DESCRIPTION OF WORK.	JOB NO.	ORDINARY TIME WROUGHT.	OVERTIME WROUGHT.	TOTAL HOURS FOR PAY BOOK.	

Overtime authorised by...

FORM B 4.

authorises the overtime, also certifies to the general accuracy of the workman's return as to the job number and time wrought.

In the time ticket of the mains section (Form B 4) there are columns for noting "where working" and "description of work," in addition to the job number, time, and overtime columns. It may be thought that the first two columns are not required, seeing that there is a job number, but it has been found that these columns are an advantage, as sometimes job numbers in a workman's hand get mixed, and, indeed, the paper sometimes gets very much soiled, so that there may be a doubt as to what is to be accepted as the job number, and the information as to where working and description of work enables the timekeeper to settle this doubt.

From the time tickets shown the time is transferred by the timekeeper into the time sheet (Form C), and the timekeeper makes up this sheet day by day, as he gets his returns, until the close of the pay week. The time sheet is not added up until the return for the time actually wrought by the employee is lodged with the timekeeper, when the sheets are added up by the timekeeper, showing the total number of hours wrought for the week by each employee. It will be noticed that the time sheet contains the workman's number, name, designation, job number, and the time spent on each job for each day, whether a man be engaged upon one job or upon four jobs. The timekeeper also notes any sum granted for travelling allowances, etc. The timekeeper does not do anything further with the sheet, but sends it in to the pay clerk in the head office, Waterloo Street, on the night of the last working day of the section, *i.e.*, as already noted, Tuesday after 5.45 p.m., or Wednesday after 5.45 p.m., for the generating and mains sections respectively. Any overtime wrought after these hours is put into the next week's pay sheet.

The pay clerk's first operation is to take the timekeeper's return and check it as soon as possible after lodging, and the hours so checked are called off to the pay clerk, who enters them against the names in the pay sheet (Form D), upon which the number, name, designation, and rate of pay of each employee has previously been printed by the "Addressograph." With this machine (No. 7 machine) a clerk can print the numbers and names, etc., of several hundreds of employees in about half an hour. It will be noticed that in the pay sheet the rate column comes before the hours wrought; the reason is that the length of the link of the "Addressograph" holding the indiarubber type which prints the pay sheet is only 3½ ins., and in order to give as much room as possible between the pay numbers and the names, etc., the rate was placed before the hours as stated.

I have already referred to the designation of the employee. Owing to the link of the "Addressograph" being so short as stated, it did not permit of the full designation or employment of the workmen being printed, such as fitter, trimmer, and so on. A series of arbitrary letters, therefore, was used to designate the classification of the workmen. This is shown in Form I. Any one referring to the pay

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ELECTRICITY DEPARTMENT.

No. of Sheets...........

TIME SHEET *for*..................................*from WEDNESDAY*.................*to TUESDAY*.................19...... ....*Timekeeper.*

NUMBER NAME										
	JOB NO.	TIME.	JOB NO.	TIME.	JOB NO.	TIME.	JOB NO.	TIME.	JOB NO.	TIME.
WED.										
THUR.										
FRID.										
SAT.										
SUN.										
MON.										
TUES.										
DEDUCTIONS ALLOWANCES TOTALS										
ABSTRACT. To be made up in General Office.										

FORM C.

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sheet, and finding: No. 240, John Smith, F.B., would see, on referring to the list, that he was a fitter. Of course, those constantly working with the sheets become familiar with the marks and do not need to refer to the list. This list is not final, and is added to from time to time as necessity arises.

The principal reason for adopting the "Addressograph," apart from the nice appearance of an apparently typewritten sheet, was that owing to certain restrictions the time allowed for making up the pay sheet was too short to permit of it being written by hand. The value of time right up to 5.45 p.m. on Tuesday has to be paid to the workmen on Thursday forenoon, and the treasurer has to have the sheets for examination and for making up his bank cheque the day prior to the pay. This means, in fact, that the pay sheet, containing about three or four hundred men, is written complete in about four hours. Were this not possible the lying time would have to be increased and an alteration made in the pay day, and this was considered inadvisable.

I have already mentioned the pay pockets being printed by the "Addressograph." The No. 7 machine, being only a one-line link machine, does not print anything that requires two or three lines. The pay pockets here shown are printed by the No. 6 machine, which can print three lines. The pay pocket of each employee has the number in the top line, the name, and £ s. d. Where the wage is a fixed weekly one it is printed in by the "Addressograph." I may say that these machines have been an enormous benefit to the department in various ways, and in printing a lot of work requiring repetition; and I may inform the members of the Local Section that every communication they receive from their secretary is addressed by one of these machines, which the Electricity Department does *ex gratia* for the Section.

The pay clerk, as mentioned, enters on the time sheet the time wrought against the several names and extends the cash values, adding any allowances or making any deductions from the pay. It will be noted that in the pay sheet there is a column "Friendly Society." This is a voluntary yearly society embracing a large proportion of the employees of the department, and, with the consent of the authorities of the department and the men interested, the fortnightly contribution to the friendly society is deducted from their pay by the pay clerk, entered on the column marked, and handed over to the treasurer of the friendly society. This obviates, of course, individual collection, and has given great satisfaction to the employees.

The "Remarks Column" is principally used for noting the length of service of each employee, and is added up week by week. Thus, an employee who had last week a service of 5 years 43 weeks, this week is entered as 5 years 44 weeks, and so on. This is one of the many things that have to be done in a Corporation department. Information is constantly being asked as to length of service of employees both collectively and individually, also other information and statistics, and it has been found necessary to have the information ready at hand.

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GLASGOW CORPORATION ELECTRICITY DEPARTMENT.

Sheet No ....

PAY SHEET.—**Generating Section.**—*Week Ending*.. *Total No. of Sheets* ....

Pay No.	Name.	Desig-nation.	Rate.	Hours.	Allowances or Deductions.	£	s.	d.	Friendly Society.			Remarks.
	Transferred	to Abstract,			£							

....*Pay Clerk.*

FORM D.

GLASGOW CORPORATION ELECTRICITY DEPARTMENT.

Abstract of Pay Sheets—**Generating Section.**—*Week Ending*..

Sheet No.	No. of Employees		Total Pay.			Friendly Society.			Remarks.
Total		£							

Certified Correct.

....*Pay Clerk.*

Checked by..

Above Wages paid

on..

by me.. *Payer.*

....*Chief Engineer.*

....*Treasurer.*

FORM E.

Each pay sheet is complete in itself; that is to say, the total is not transferred to the next sheet, but to an abstract (Form E). This abstract shows the number of employees and the total pay in each sheet, also the amount deducted for the friendly society, and is certified as correct by the pay clerk and his assistant; the representative of the treasurer who pays the employees also signs; the chief engineer and the treasurer sign, certifying the general accuracy, and this abstract, along with the pay sheets and the allocation sheet subsequently referred to, is presented to the auditors when auditing the books. The benefit of having individual pay sheets is, that should an error occur in a sheet affecting the total additions of that sheet, it does not mean that all the subsequent sheets are wrong and will require to be corrected also. The erroneous sheet can be destroyed and a new sheet printed in a few minutes, and the time filled in as before stated. Each sheet is numbered, and the total number of sheets forming each pay list is also shown.

After the pay sheet is made up and sent to the treasurer the allocation of the total pay is proceeded with. The time sheets (Form C) are taken in hand, and the time of each employee is abstracted at the foot of the sheet, and the time spent on the various jobs, also the cash value of that time, is extended. The pay clerk's assistant who makes up this abstract gets the rates of pay from the pay sheet, and notes the total pay paid to the employee also from the pay sheet. The abstract must show the same total in detail against the various jobs which the workmen may happen to be engaged upon. It is evident that this being done, the cash value of the employees' time expended on the various jobs when added all together will agree accurately to a penny with the total of the pay sheet.

When the time spent on the various jobs by the respective employees is made up, these amounts are abstracted for the purposes of costing on Form F (abstract of wages, week ending ——). This abstract of wages shows the time sheet from which the information has been drawn, the workman's number, name, designation, hours, rate, and £ s. d. These sheets when completed are added, and the total abstracted on a separate sheet.

Form G (Abstract of Wages, Treasurer's Allocation).—The abstract (Form G) forms the basis of the allocation for the treasurer, who requires only the total amounts spent under the various principal accounts such as shown in Form A. On the treasurer's allocation sheet, therefore, all the jobs under these principal headings are grouped together and added, and the amounts so obtained are transferred to the printed allocation of wages sheet (Form H). These sheets are certified by the pay clerk and by his assistant, and countersigned by the chief clerk for the correctness of the allocation, and also signed by the chief engineer as authorising the expenditure. Of course the totals of these allocation sheets are the totals of the pay sheet abstract.

All the notes up to this point have been in connection with the time and pay of the employees paid by the hour. Those employees paid a

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ELECTRICITY DEPARTMENT—GENERAL OFFICE.

No. 975

Abstract of Wages, week ending.. *Job No*...................

TIME.	WORKMAN'S No.	NAME.	DESIGNATION.	HOURS.	RATE.	£	s.	d.	

FORM F.

ABSTRACT OF WAGES—TREASURER'S ALLOCATIONS.

497

Week ending...

FORM G.

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standing weekly wage do not require to lodge a daily time sheet, as the work upon which such men are engaged is practically constant, and all that is necessary in their case is to ascertain that they have been at work, and this is easily done, as they, in common with all the other employees of the department, record their attendance upon the Dey time recorder. The records of these recorders are also used to compare the statements of the hours wrought by the men who are paid by the hour.

The pay sheets with relative abstracts are punched and put in a binder and sent to the treasurer for checking, as already noted.

The pay clerk, along with the treasurer's representative, gets a cheque on the bank from the treasurer, and makes up the pay from the pay sheets. These pays are placed into the pay pockets already referred to, and at the proper times and places are handed over to the workmen on their presenting a metal check corresponding to their name and pay number.

When a sufficient number of weeks' pay sheets have been collected they are bound together in book form and kept for reference.

The time sheets (Form C) are also stitched together for reference.

The Forms F are punched and put in a binder and sent to the costing office for the individual costs of the several jobs. I may say that there are at present about four hundred jobs going on each week of which the separate cost is required. A few months ago, when we were busy, there were about six hundred. The costing office enters into the cost sheets, along with the material obtained from the stores for the same jobs, the value of the time noted on Form F, and thus the total time and material expended on each job is shown.

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GLASGOW CORPORATION

GENERATING SECTION.—*Allocation*

CAPITAL ACCOUNTS.						
Lands and Buildings.						
Port Dundas						
Pollokshaws Road						
Waterloo Street						
Kelvinside						
John Street						
Byres Road						
Springburn						
Dalmarnock						
Cathedral Street						
Machinery and Plant.						
Port Dundas						
Pollokshaws Road						
Waterloo Street						
Kelvinside						
John Street						
Byres Road						
Springburn						
Dalmarnock						
Cathedral Street						
Accumulators.						
Port Dundas						
Pollokshaws Road						
New Mains						
Meters and Indicators						
Electrical Instruments. All Stations ...						
Counting House Furniture. All Stations						
TOTAL OF CAPITAL ITEMS						

FORM H.

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ELECTRICITY DEPARTMENT

of Wages for Week ending..................................

REVENUE ACCOUNTS.						
Salaries.—Engineers' Department ...						
Superintendents at Works ...						
Wages at Generating and Sub-Stations.						
Port Dundas						
Pollokshaws Road						
Waterloo Street						
Kelvinside						
John Street						
Byres Road						
Springburn						
Dalmarnock						
Cathedral Street						
Repairs to Buildings.						
Port Dundas						
Pollokshaws Road						
Waterloo Street						
Kelvinside						
John Street						
Byres Road						
Springburn						
Dalmarnock						
Cathedral Street						
Repairs to Machinery and Plant.						
Port Dundas						
Pollokshaws Road						
Waterloo Street						
Kelvinside						
John Street						
Byres Road						
Springburn						
Dalmarnock						
Cathedral Street						
Repairs to Accumulators.						
Port Dundas						
Pollokshaws Road						
Repairs to Mains						
Repairs to Meters and Indicators ...						
Attending and Repairing Public Arc Lamps						
Private Street and Stair Lighting ...						
General Establishment Charges ...						
Total						

Pay Clerk..

Checked by..

Chief Clerk..   ....*Chief Engineer.*

Date..

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GLASGOW CORPORATION ELECTRICITY DEPARTMENT.

STAFF, TRADESMEN, AND WORKMEN'S DESIGNATIONS

Used in connection with Time, Pay Books, and Costing.

Arc Lamp Foreman	A. B.
Arc Lamp Foreman's Assistant ...	A. C.
Arc Lamp Fitter	A. D.
Arc Lamp Inspector	A. E.
Arc Lamp Repairer	A. F.
Arc Lamp Trimmer	A. G.
Arc Lamp Trimmer's Mate	A. H.
Arc Lamp Labourer (see Labourer)	
Arc Lamp Wireman	A. I.
Battery Attendant	B. A.
Bench Hand	B. C.
Blacksmith	B. D.
Boxman, Foreman	B. E.
Boxman, High Tension	B. F.
Boxman	B. G.
Brassfinisher	B. H.
Bricklayer	B. I.
Bricklayer, Apprentice	B. K.
Boiler House, Foreman	B. L.
Canvasser	C. A.
Carpenter	C. B.
Cleaner, Engine	C. D.
Cleaner, Dynamo	C. E.
Clerk	C. F.
Clerk, Complaint	C. G.
Clerk, Cost	C. H.
Clerk, General Office...	C. I.
Clerk, Mains	C. K.
Clerk, Meter and Laboratory ...	C. L.
Clerk, Stores	C. M.
Clerk, Pay	C. N.
Clerk, Time	C. O.
Coppersmith	C. P.
Craneman	C. Q.
Driver, Engine	D. A.
Draughtsman	D. B.
Draughtsman, Apprentice	D. C.
Electrician	E. A.
Emergency Man	E. B.
Engineer, Station	E. C.
Engineer, Assistant Station ...	E. D.
Engineer in charge	E. F.
Emergency Man's Mate	E. G.
Fitter, Foreman	F. A.
Fitter	F. B.
Fitter, Improver	F. C.
Fireman, Foreman (see Boiler)	
Fireman	F. E.
Greaser	G. A.
Hammerman	H. A.
Instrument Repairer...	I. A.
Jointer, Foreman	J. A.
Jointer, Assistant Foreman	J. B.
Jointer	J. C.
Jointer's Mate	J. D.
Joiners	J. E.
Labourer, Arc Lamp	L. A.
Labourer, Bricklayer...	L. B.
Labourer, General	L. C.
Labourer, Jointer's	L. D.
Labourer, Laboratory	L. E.
Labourer, Mason's	L. F.
Labourer, Squad Foreman	L. G.
Labourer, Squad Leading Hand ...	L. H.
Labourer, Squad General	L. I.
Labourer, Stores	L. K.
Labourer, Wireman	L. M.
Laboratory, Superintendent of ...	L. N.
Laboratory, Assistant	L. O.
Machineman	M. A.
Master of Works	M. B.
Master of Works, Assistant ...	M. C.
Mason, Foreman	M. D.
Mason	M. E.
Mechanic	M. F.
Messenger	M. G.
Meter Inspector	M. H.
Meter Workshop Foreman... ...	M. I.
Moulder...	M. K.
Motorman	M. L.
Office Porter	O. A.
Office Cleaner	O. B.
Painter, Foreman	P. A.
Painter	P. B.
Patternmaker	P. C.
Plasterer	P. D.
Plumber	P. E.
Rigger	R. A.
Sailmaker	S. A.
Stores, Superintendent of	S. B.
Storeman, Head	S. C.
Storeman, Assistant	S. D.
Storeman	S. E.
Superintendent, District Mains ...	S. F.
Superintendent, District Mains, Assistant	S. G.
Switchboard Attendant (see Engineer)	
Surveyor	S. K.
Surveyor, Assistant	S. L.
Squad Superintendent	S. M.
Station Foreman	S. N.
Squad Foreman (see Labourer)	
Stores Superintendent Assistant ...	S. O.
Timekeeper	T. A.
Tinsmith	T. B.
Toolmaker	T. C.
Trimmer, Coal...	T. D.
Turner	T. E.
Telephone Operator	T. F.
Watchman, Foreman	W. A.
Watchman	W. B.
Wireman, Foreman	W. C.
Wireman (see also Arc Lamp Wireman)	W. D.
Wireman's Mate	W. E.
Workshop Foreman	W. F.

NOTE.—Timekeepers will be given Designation Letters for any other class of Employee not already on above List on application to the Chief Clerk.

FORM I.

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Joint Discussion on Messrs. Denholm's and Maccall's Papers.

Mr. W. W. Lackie: After hearing the very interesting papers from Mr. Maccall and Mr. Denholm it must be a matter for congratulation to those members who are ratepayers to know that the Electricity Department of the Corporation is certainly up-to-date in their system of stores and cost-keeping. It is surprising to learn that there are about sixty jobs inside the works which cannot conveniently be handed to outside contractors. The working of the pay sheet does not cost 1 per cent. of the total pay bill, and the stores cost about 4 per cent. on their total turnover. Mr. Lackie.

Mr. W. H. Tittensor: As the auditors might come in at the end of six or twelve months and merely glance through the books, I should like to know if the authors are able to check *all* the books. In a huge system like theirs they have one great advantage—they can afford to spend money to do things properly. They have experts in each of their departments, and it is not as in some small undertakings, where one clerk has to do everything, with a chief engineer to help him. The question of time sheets is very important, and I must congratulate the department on the way in which the accountants' department seems to work in with the engineering department. One of the great difficulties is to get the accountants' department to realise the importance of analysis of costs. The accountants say, "Why do you bother about wasting time on the station costs now, when the money is spent?" If this were not done there would be no comparison of costs by the engineer and nothing to induce him to reduce them. It is all very well for a workman to give a time sheet, but in some of the small stations many of the standing-wage men have to do some work and supervise repairs, etc., and it is not fair that the generating department should bear all these costs. In connection with a tramway department and a power station adjoining there is a trained man in charge, and there is no reason why he should not look after some of the work in the car shed. There must be an allocation of his time. If he is given a time sheet there is trouble, and I have had to face that trouble. The way in which we got over that was to call the sheets "Staff allocation sheets," and then the difficulty was that we could not get the accurate value from the number of hours. We therefore took the whole week and divided it up into percentages for each job, and so allocated the true amount of time given by the staff to the repair department. As regards stores, the storekeeper has two files with the requisition form No. 1, showing all goods to be delivered. What happens when a manufacturer delivers only a portion of the work on the requisition forms? Mr. Denholm says: "We hear a great deal about organised publicity departments (they are generally called commercial departments) for the purpose of getting consumers on the mains, but any good such a department might do is frequently nullified by the unbusinesslike way in which its ordinary work is carried on." I presume that Mr. Denholm speaks for concerns under Municipal Mr. Tittensor.

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Mr. Tittensor. government, and I quite agree with him, but if these other departments are company concerns ruled by business men I do not think that that criticism applies. Mr. Denholm says that cards have many objectionable features, and I quite agree with that. This is a point on which there are many opinions, and I would be glad if Mr. Denholm would mention some of the objections that he has to cards. Some people think that the card index system is a new thing and an American invention, but it is not very new. It is a thoroughly good thing when properly applied, and I know a man who has used it in this country successfully for nearly fifty years.

Mr. M'Whirter. Mr. W. M'WHIRTER: There is nothing more interesting to any one in business, even in a small way, than the correct keeping of costs, both of wages and material, and there is no doubt at all that it is a thing that is very often badly and indifferently done. In my own business we have a very large number of jobs, and every job that goes into the place has a number. The system is not so elaborate as the Corporation's, and we have the same troubles that Mr. Maccall and Mr. Denholm have pointed out, namely, the difficulty of getting workmen to fill in their time against the correct jobs. Formerly each man had a time book, and we found that if a man could get his 9½ or 10 hours per day, or the total up to 54 hours per week, he was quite satisfied, and it often was found when they came to render accounts that the time on the job was impossible. Some two years ago we purchased one of the Kosmoid time-recorders, and now when a man gets a job he also gets a slip with the number of the job and just sufficient details to let him know what it is. He goes to the recorder, puts down his own and the job number, and presses the key. If in the course of the day he is taken off owing to some urgent repair coming in, he gets a new slip and returns to the time-recorder, puts down his own and the first number, presses down the key, and immediately puts on the new job number. We find that this is a most useful system, and we rarely have any cause to complain. Of course, with the men outside we cannot use it, but in the works, where they are coming and going to a number of jobs, we find it extremely useful and satisfactory. In the same way in the matter of stores we carry out the same system. If a man requires material for his work he draws it on that job number; they have job tickets, but they call them job sheets. The front of the sheet has the material and the rate columns and two sets of money columns. When a man draws his stores these are put against the job in the storekeeper's book, in which there may be a dozen jobs on one page. The next morning the storekeeper goes through his book and allocates the material and time to the various jobs. Costing is of no use if it does not show the money spent on a job at any moment. I think that Mr. Denholm's last paragraph puts the whole thing in a nutshell.

Mr. M'Dougall. Mr. A. C. M'DOUGALL: The system adopted at Coplawhill is that the timekeepers go round and get the allocation of the time of each man, as some men are not capable of recording their time properly, and others are careless. While the workmen give the number, the time-

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Mr. M'Dougall.

keeper, who knows the job numbers, can check it in the event of a mistake being made. Before any work is undertaken at the car works an order is made out by the party who desires the work done. This is certified by the chief engineer and passed on to the works manager, who in turn issues written instructions to the foremen concerned. These instructions bear the number to which all time and all material in connection with that expenditure is to be allocated. The time allocation sheets for the whole week are in one, and there is a column at the side with sufficient space for about ten job numbers. The men's time is allocated and added across at the foot. That time is transferred to the wages sheet and abstracted into a general abstract of workmen's time, and the total amount brought out is compared with the total wages paid by the pay clerk, and in that way ensures that every man's time is allocated. The material used is written up on forms with the job number entered. These entries are copied from the forms that are made out and are passed in to the storekeeper, and the total is abstracted weekly and posted to the respective accounts in a similar way to that detailed by Mr. Denholm. On the keeping of accounts Mr. Denholm points out the card system. It has many advantages for some purposes, but I do not think it would be a success in the keeping of stores accounts. The system Mr. Denholm has spoken of is a system that has been in existence in the tramway department for some years—the loose-leaf principle. Where there is an enormous number of postings to make the card system is objectionable, apart from the fact that it is easy for a card to be taken out and all trace of it lost.

The practice in the tramways is to price out the material at the actual cost rate. The pricing is done from the stock accounts. The stock accounts are posted from the "goods received" sheets, which are a record of all material received at the stores, and these are checked with the invoices for goods purchased. I think it is safe to take the cost price, because while the value of some things may have risen there will be other things purchased cheaper than current rate, and the only safe way of accounting is to deal with the cost price; to attempt to price every individual item at rates due to market fluctuations causes endless trouble in balancing.

Mr. Walker.

Mr. FRANK WALKER: I have had a good deal to do with estimating and costing systems in connection with manufacturing work. One feature, usually adopted in such works, does not appear to be included in the system described in the paper. This is the giving to the storekeeper, when a job is put in hand, a complete specification of all material which will be required, which enables the storekeeper to check his stock and to order promptly all material needed from outside. It also serves to prevent too much material being issued, and, further, may be used by the cost clerk to ensure all material being included in his costs.

With reference to the card system, of which several speakers have spoken deprecatingly, I have had experience of a place where work done on the old book system by twelve men is now being done on the card system by six men, and more efficiently.

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Mr. Walker.

In connection with engineering costs there seems to be always trouble arising from one cause—viz., the human factor. The system adopted may be perfect and simple, yet mistakes are often made owing to the books or cards being kept by men who are non-technical; for instance, in checking accounts I have found £20 for french polishing charged to an account for a cast-iron tank. In accounts showing costs of dynamos two armatures may be included—or in other cases none at all. In accounts for large contracts I have known items, hundreds of pounds in value, included twice.

One great source of trouble of this kind lies in the same article being described on different occasions by different names. The clerks often do not know the articles themselves. If one voucher specifies an article by one name, and another voucher specifies it differently, confusion and trouble may, and usually do, result.

Considerable experience in clearing up muddles, arising from difficulties similar to those indicated, leads to the conclusion that all cost accounts should be gone over by a technical man—one thoroughly familiar with all the materials used, and with the design, as well as the legitimate costs of the work under consideration.

Mr. Maccall.

Mr. MACCALL (*in reply*): The auditors in Glasgow are chartered accountants of high standing in the city, with an experience of thirty years, and they are very particular. I do not think that any rough statement would satisfy them. They must be satisfied that the money is properly spent and allocated. It is not impossible to allocate those men who are paid fixed wages and are engaged on more jobs than one. I am perfectly well acquainted with the time recorder spoken of by Mr. M'Whirter, and I know that it is used in such works as those of Messrs. Bruce, Peebles & Company. I am aware of the system mentioned in Mr. M'Dougall's remarks in making up the tramway sheets, but it would not suit the requirements of my department. I will not say that my system is better, but it meets all the necessities of all the officials interested. The superintendents of stations and of the mains department are responsible for the general accuracy of the costs of the jobs, including allocation of the time of men under their supervision.

With reference to pricing goods for jobs, we fix the price thus: Material may be purchased at, say, 20s., and some of this material may be used and charged up at this price. More material may then be purchased at, say, 22s. A balance is struck showing the cost of what is in stock, and an average price fixed, and until more purchases are made all goods go out of store at the last fixed rate. Under this system of working we were only some £115 short in a turnover of £100,000. The number of separate articles in the stores was 11,200 when last ascertained.

The trouble spoken of by Mr. Walker, of the material being twice charged to the same job, could not very well occur in connection with our stock and costing system, unless the material was twice obtained by the workman, a not very likely thing. The stores despatch note

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goes direct to the cost clerk, who compares it with the workman's statement of material said to be used by him, and any discrepancy is at once noted. The confusion as to description of material also mentioned by Mr. Walker is not likely to arise with us, as the stock is all listed and indicated in the stores despatch notes and books by a letter and number, so that a mis-description on a workman's order on the store would not be copied, and therefore would not lead to error. Mr. Maccall.

It is, I think, a good thing that so many engineers, either company or corporate, are so interested in the matter of cost and stores keeping, and the proper allocation of workmen's time. I do not quite agree with Mr. Tittensor, possibly because I am an accountant, in his remarks regarding the indifference of accountants to costs. It is generally believed that accountants want to know too much about costs, and are voted nuisances by engineers, but this, of course, does not apply to the Glasgow Corporation Electricity Department.

Mr. DENHOLM (*in reply*) : There is no doubt some difficulty existing in getting a proper system carried out in the smaller stations, but the remedy seems to be to select men for the work who have had some general experience, and a knowledge of engineers' stores. Requisitions partly executed could be retained on file No. 1. The objections stated to card systems apply only to stock records. The card index is used with success for meter department records, and for recording consumers' applications, etc. Mr. Denholm.

Mr. Walker dealt with the troubles of a manufacturing concern. With such I have had very little experience, but the engineers responsible for the work of the various departments should go over the cost sheets and certify them. The question of clerks having no knowledge of the material is always a drawback. Why not give the clerks a spell in the shops and stores before putting them on to the Stores and Cost Office Staffs?

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MANCHESTER LOCAL SECTION.

MAGNETIC OSCILLATIONS IN ALTERNATORS.

By GLADSTONE W. WORRALL, M.Sc., M.Eng., Assoc. Member.

(*Paper read February* 5, 1907.)

The present paper is a continuation of one* which the author had the honour of reading before this section of the Institution of Electrical Engineers in which were recorded results obtained by an investigation of the periodic variations in the magnetic field of a 3-phase generator, carried out by Mr. Thomas F. Wall and himself.

The machine employed in the present investigation was a 3-phase mesh connected alternator with rotating armature, 4 poles, 44 teeth, speed 1,200 r.p.m. P.D. on open circuit 159 volts. Full load current in mesh 15 amperes. Two armatures were experimented upon,

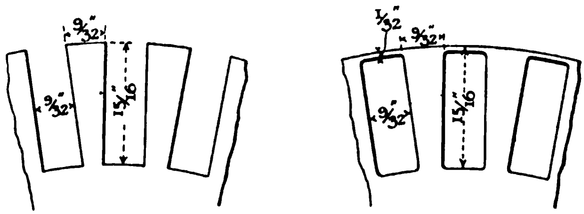

FIG. 1.—Shape of Slot.

similar in every respect, except that the slots of one were open and those of the other closed, and the size of wire employed in the latter armature was slightly smaller than that employed in the former so as to allow of the same number of conductors with the same width and depth of slot. The dimensions of slots are given in Fig. 1.

The pole-pieces and limbs of the machine were laminated, but alternate laminations were cut short, so as to fringe the pole tips.

The previous investigation was limited to the oscillations on the pole face due to the teeth of an armature with semi-closed slots, and the results were so remarkable that the present author was induced not only to repeat the investigation on other types of machine, but also

* *Journal, Institution of Electrical Engineers*, vol. 37.

to extend them to the oscillations due to the teeth in the interpolar space, and to those due to armature reaction in the same parts of the machine, as well as to the penetration of the oscillations into the main magnetic circuit.

The oscillations were observed as in the previous investigation by means of the E.M.F.'s induced in certain search coils.

The positions of the search coils are shown in Fig. 2.

Eleven search coils were attached to the pole face parallel to the axis of the armature, one side of each to a N. pole, and the other in a corresponding position to an adjacent S. pole.

Each of these search coils consisted of one turn except I.L and I.T, which were of six turns each, and II.L and II.T, which were of three turns each. One search coil of eight turns was wrapped round a

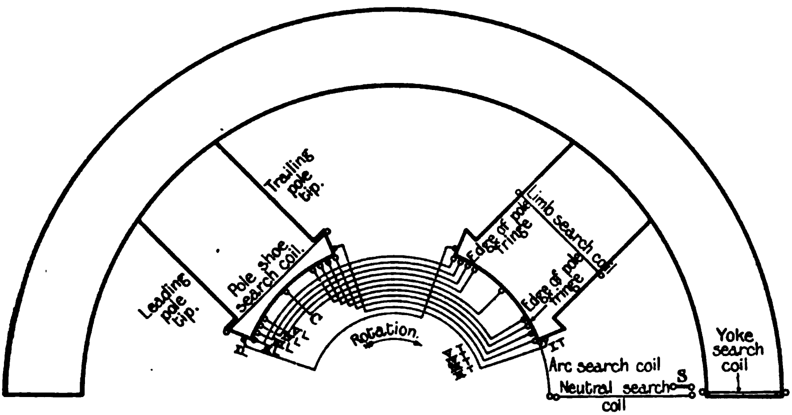

FIG. 2.—Position of the Search Coils.

pole shoe, one of forty turns round a limb of the magnets, mid-way between the pole and the yoke, and one of forty turns round the yoke. A search coil of thirty turns was placed in the neutral plane, and one of ten turns in the interpolar space, with one side against the trailing tip of a pole and the other side in the neutral plane.

The E.M.F.'s induced were photographically recorded by means of a Duddell high frequency double oscillograph and revolving film camera.

The machine was run on open circuit and on non-inductive and inductive loads, in each case both half and full.

Oscillations on the Pole Face Due to the Armature Teeth.

It was found in the previous investigation that a magnetic oscillation consists of two movements of the flux; these movements are one in the same direction as the motion of the armature, the other in the opposite direction. The former appeared to be due to hysteresis in

the teeth, and was described as the "drag," the latter was a movement across the slot, and was described as the "flash." In the present investigation these observations were confirmed.

The waves of E.M.F. induced in the search coils of the previous investigation were somewhat irregular in shape, but those observed in the present case, with the different type of machine, were fairly regular, as will be seen later on by reference to the diagrams. It may be here recalled that the area of a half wave of E.M.F. represents the magnitude of the moving flux, and that the flux moving due to a "flash" is in all cases equal to that due to a "drag." The actual values of the fluxes in the present investigation are given in Table I. In Table II. these values are expressed as a percentage of the flux entering a tooth when the latter is under a search coil.

TABLE Ia.

Actual values of the flux moving at various points of the pole face.

OPEN SLOTS.

Coil.	Open Circuit.	Non-Inductive Load.		Inductive Load.	
		Half.	Full.	Half.	Full.
I.L.	1,700	2,300	2,800	2,400	1,400
II.L.	9,200	6,200	9,500	10,000	8,500
III.L	38,000	30,000	30,000	32,000	32,000
IV.L.	25,000	21,000	29,000	25,000	24,000
V.L.	38,000	25,000	29,000	38,000	28,000
C.	28,000	24,000	33,500	28,000	24,000
V.T.	37,000	33,000	34,000	43,000	28,000
IV.T.	24,000	27,000	34,000	31,000	16,000
III.T.	24,000	27,000	34,000	36,000	30,000
II.T.	12,000	12,000	16,000	14,000	10,000
I.T.	1,700	3,000	2,800	2,200	2,100

The high percentages given in the table for the oscillating fluxes indicate the extent to which they are bunched in the tips of the teeth, and the same table shows that the magnitude of the oscillating flux at any given point on the pole face varies with the load.

This variation generally follows the well-known laws of armature

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reaction, according to which the flux on the non-inductive load is less under the leading tip and greater under the trailing tip of the pole face

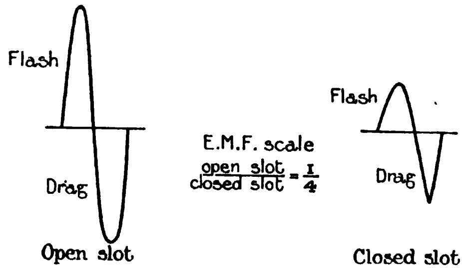

FIG. 3.—E.M.F. Waves in Search Coil III.L. on Open Circuit.

than on open circuit, and on the inductive loads is weakened over the whole pole face.

TABLE IB.

Actual values of the flux moving at various points of the pole face.

CLOSED SLOTS.

Coil.	Open Circuit.	Non-Inductive Load.		Inductive Load.	
		Half.	Full.	Half.	Full.
I.L.	300	650	700	360	360
II.L.	1,700	1,500	1,500	1,500	1,400
III.L.	3,600	2,700	2,200	3,600	3,200
IV.L.	1,900	1,500	1,800	1,600	1,300
V.L.	2,200	2,200	1,700	800	2,200
C.	900	2,000	2,000	800	800
V.T.	2,200	2,700	2,200	2,700	2,500
IV.T.	1,500	2,300	2,800	1,000	1,000
III.T.	3,000	3,400	3,200	2,700	3,800
II.T.	1,000	1,000	1,400	1,000	1,200
I.T.	400	700	600	300	300

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TABLE IIA.

Flux moving at various points of the pole face expressed as a percentage of that entering a tooth on open circuit.

OPEN SLOTS.

Coil.	Open Circuit.	Non-Inductive Load.		Inductive Load.	
		Half.	Full.	Half.	Full.
I.L.	2·9	4·0	4·8	4·0	2·6
II.L.	16·0	11·0	16·0	17·0	15·0
III.L.	57·0	44·0	44·0	48·0	48·0
IV.L.	37·0	31·0	44·0	37·0	36·0
V.L.	58·0	37·0	44·0	58·0	44·0
C.	46·0	40·0	56·0	46·0	40·0
V.T.	56·0	50·0	53·0	66·0	42·0
IV.T.	37·0	40·0	53·0	48·0	25·0
III.T.	41·0	46·0	58·0	62·0	52·0
II.T.	24·0	24·0	32·0	28·0	20·0
I.T.	3·4	2·6	5·3	4·4	4·0

The duration of the movement of the flux during the "flash" was, under all circumstances in which the slots were open, equal to that during the "drag." But the E.M.F. induced during a "flash" was under the same circumstances, greater than that during a "drag," although, as has been stated, the fluxes moving in the two cases were equal. This apparent anomaly is accounted for by the difference in shape between the half wave due to a "flash" and that due to a "drag." The half wave due to a "flash," as will be seen from Fig. 3, is angular, slightly rounded at the vertex, while that due to a "drag" is curvilinear. This angularity of the "flash" shows that the rates of increase and decrease of the flashing are constant and equal during almost the whole of its duration. It is interesting to compare the angularity of the "flash" in the case of the open slot with the curvilinear shape of the same in the case of the closed slot (Fig. 3). The probable cause of this difference lies in the opposition to the "flash" offered by the bridge of the closed slot, and the free course open to it through the air-space of the open slot.

It was pointed out in connection with the previous investigation

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TABLE IIB.

Flux moving at various points of the pole face expressed as a percentage of that entering a tooth on open circuit.

CLOSED SLOTS.

Coil.	Open Circuit.	Non-Inductive Load.		Inductive Load.	
		Half.	Full.	Half.	Full.
I.L.	0·56	1·2	1·3	0·66	0·66
II.L.	3.20	2·8	2·8	2·80	2·60
III.L.	5·70	4·2	3·4	5·70	5·00
IV.L.	2·60	2·1	2·6	2·60	2·00
V.L.	3·70	3·7	2·8	1·20	3·70
C.	1·50	3.3	3·3	1·30	1·50
V.T.	3·30	4·1	3·3	4·10	3·70
IV.T.	2·40	3·7	4·4	1·60	1·60
III.T.	4·90	5·6	5·0	4·40	6·20
II.T.	2·10	2·1	3·2	2·10	2·60
I.T.	0·90	1·6	1·2	0·66	0·66

that under given conditions the local flux produced by the current in a conductor increases the duration of the "flash" and reduces that of the "drag." As that investigation was limited to the semi-closed slot, it was interesting to note in connection with the present one whether or not the phenomenon of alteration of relative duration of "flash" and "drag" would reappear.

The phenomenon did occur when the closed slot was in use. It did not occur when the open slot was in use, but when this latter was the case the phases of the oscillations relative to the armature appeared to become displaced.

This phase displacement will form a subject of future investigation, but assuming the observation to be correct, it is interesting to note the difference in the action of the local flux produced by the armature current in the case of the two shapes of slot. The cause of the difference may be due to the path taken by the local flux. There are two paths open, and the one taken by the major portion of the flux would be that of least reluctance. When the slot is entirely closed the path of least reluctance is that directly across it, which

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is iron all the way (Fig. 4). When the slot is semi-closed the path of least reluctance is still across it, provided the slot opening be not too great, but, when the slot is entirely open and its width greater than twice the air-gap, the path of least reluctance is from the armature to pole face and back.

The phase displacement assumed consists in a slight change in the position of the centre of the tooth and slot respectively, in relation to the search coil on the pole face, when the E.M.F. induced in the latter is maximum.

The probable cause may be as follows. The distribution of flux over the pole face is not uniform, most of it being concentrated at points opposite to the armature teeth.

The greater degree of intensity at the tooth top may be referred to as the crest of the flux. Now on open circuit the centre of the crest is

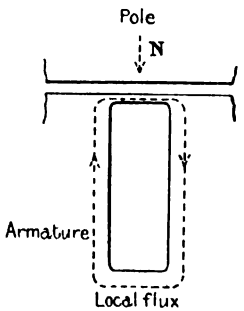

FIG. 4.—Path of Local Flux with Closed Slot.

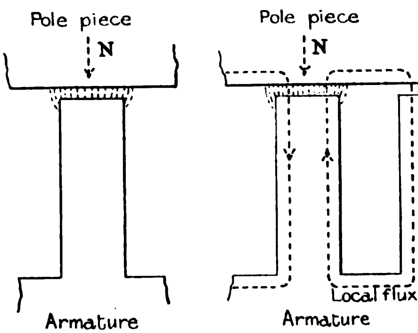

FIG. 5.—Flux Displacement.

vertical to the centre of the tooth, and with open slots when a current is flowing through the conductors on either side of the tooth, one side of the crest is increased in intensity, while the other side is reduced as illustrated in Fig. 5. The effect of this is to shift the centre of the crest to one side. This may be called flux displacement. It was found by means of a contact maker of special design, that the maximum E.M.F. due to the "drag" is induced in a coil when the centre of a tooth is vertical to it. So that when the flux displacement takes place the position of the tooth relative to a coil when the maximum E.M.F. is induced shifts in a corresponding degree, which is the phenomenon of phase displacement.

OSCILLATIONS IN THE INTERPOLAR SPACE DUE TO THE TEETH.

It would appear that wherever else magnetic oscillations might occur, they would not be likely to occur in the interpolar space.

During the present investigation, however, it was observed that considerable oscillations occurred in the neutral coil, but it was

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thought that these might be due to leakage flux across the interpolar space. To determine this a small search coil S (Fig. 2) was employed.

The search coil was placed first at the yoke side of the neutral coil, but no oscillations due to the teeth were observed in it; then at the armature side of the neutral coil, and oscillations were observed in it which in magnitude were almost equal to those in the neutral coil itself. It thus appeared that the oscillations were not due to the leakage flux, at least mainly, but were produced directly by the armature teeth in the neutral plane.

The explanation of this phenomenon may be that some of the main flux, instead of penetrating into the armature below the slots, passes from pole to pole alternately through tooth and slot, and that the flux when passing through a tooth is concentrated in the tooth, but when passing through a slot not only fills the slot but spreads out above the armature, as shown in Fig. 6.

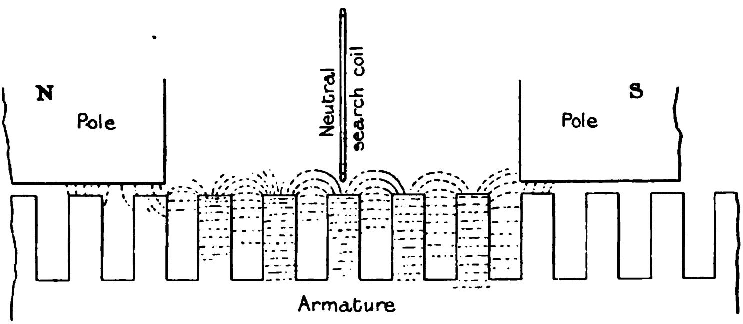

FIG. 6.—Oscillations due to Teeth in Neutral Plane.

Thus when a slot is opposite the neutral coil some of the flux would link the coil, but as a tooth approaches, the flux would be withdrawn. This explanation is the more likely because when the search coil S was placed so that the distance between it and the neutral coil was exactly equal to one-half the pitch of the teeth the phase difference between the oscillations observed in the two coils proved to be 180°. Thus much for the cause of the existence of the oscillations. Their magnitude in the case of open slots was approximately the same on load as on open circuit, and in the case of closed slots the same equality was maintained, except on inductive loads, when their magnitude was greater than an open circuit.

This rise in magnitude in the case of inductive loads with closed slots is shown in Fig. 7, and may be due to the circumstance that it is only on such loads that current is carried by the conductors in the slots as they pass the neutral search coil.

Now, on open circuit the main flux in passing from tooth to tooth crowds into the bridge of the closed slot. But on inductive load the local flux which the current produces so increases the density in the

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bridge that more of the flux is forced to spread out above the surface of the armature, and so link the neutral coil and increase the oscillations occurring in it.

The oscillations in the "arc" search coil (Fig. 2), were greater in magnitude than those observed in the neutral search coil, and although partly due to the same cause as these latter, were mainly due to the movement of the fringing flux at the trailing tip of the pole.

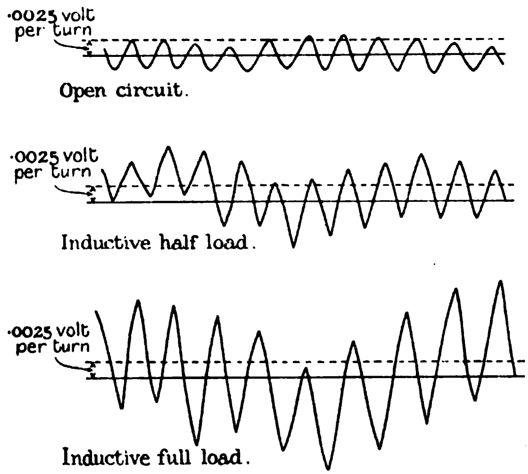

FIG. 7.—E.M.F. Waves in Neutral Coil with Closed Slots.

OSCILLATIONS DUE TO ARMATURE REACTION.

Under all circumstances of the experiments throughout the investigation oscillations were observed in all the search coils superposed on those due to the teeth. They are of three classes :—

1. Irregular, with the cycle of irregularities recurring at each revolution.
2. Regular, and three times the frequency of the machine.
3. Regular, and twice the frequency of the machine.

Some record of the first class will be found in the whole of the diagrams. They appear to be due, if not to some irregularity in construction, to the reaction of the flux produced by a local current in the armature. This current arises from a slight potential difference between the opposite points of the winding connected to the same slip-ring.

Oscillations of the second class only occurred on load, and are given in Fig. 8. They were greatest in the neutral search coil on non-inductive loads, and in the pole-shoe coil, equal on both inductive and non-inductive loads. Thus they appear to be due to armature reaction. It

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is generally held that the armature reaction of a balanced 3-phase current is a field constant in magnitude and stationary in space, but the second class of oscillations exhibited in the present investigations are quite incompatible with the idea of a constant and stationary field, and the correct explanation of 3-phase armature reaction appears to be that as the phases differ in their individual relation to the pole-piece, they differ also in the reluctance of their paths. The magnitude of the

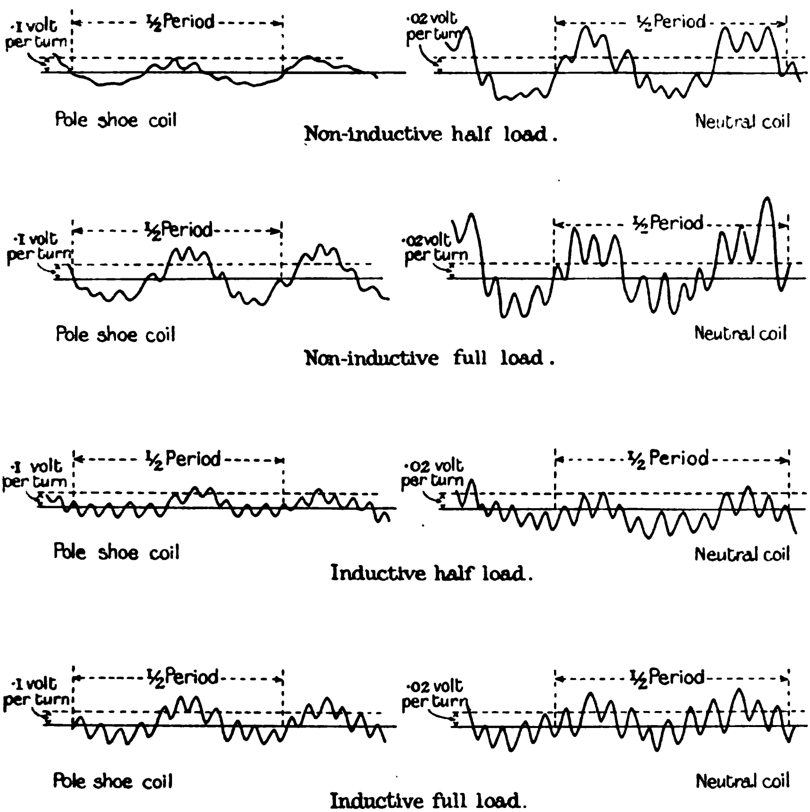

FIG. 8.—Armature Reaction on Balanced Loads, Open Slots.

reacting field, therefore, periodically varies, and since during the passage of the three phases under a pole-piece there are three symmetrical positions in which the reacting field attains its maximum value, the reacting field of the armature current is subject to an oscillation of three times the frequency of the machine.

The cause of these oscillations being as above stated, a maximum in the neutral search coil on non-inductive loads appears to be that in this case the line of resultant flux lies in the neutral plane. The cause

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of the oscillations in the pole-shoe coil being equal on non-inductive and inductive loads, appears to be that in both cases the whole of the reacting flux enters the pole-piece.

The third class of oscillations were produced by unbalanced loads. It was not originally intended that unbalanced loads should come within the scope of this paper, but, during the investigation with balanced loads, a suspicion arose that the oscillations of the second class were due to the three phases not being exactly 120° apart, for the number of slots of the machine used was not divisible by six.

To test the matter an attempt was made to increase the magnitude of the oscillations by unbalancing the load. The attempt, however, proved futile, and the suspicion proved to be incorrect, for instead of the oscillations previously observed becoming increased in magnitude, this third class of oscillations appeared (Fig. 9). The unbalanced load

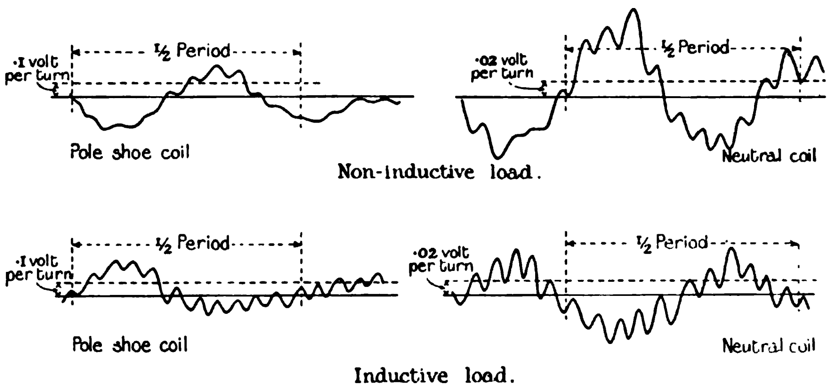

FIG. 9.—Armature Reaction on Unbalanced Loads, Open Slots. One Phase, Full Load; Two Phases, Half Load.

was produced by running the machine on both non-inductive and inductive loads, with one phase on full load and the other two on half, and also with one phase on half and the other two on full load.

In order to explain the presence of the oscillations of the third class it was found convenient to consider an unbalanced load as a balanced load plus an excess current in one or two of its phases. Now it is to this excess current that the oscillations observed are probably due. They are, as has been stated, of twice the frequency of the machine, and therefore appear to arise from a complete oscillation of magnetism being produced as the phase carrying the excess current approaches towards, and recedes from, each successive pole.

This explanation appears the more likely to be correct when it is remembered that in an inductor alternator the E.M.F. is produced by a magnetic variation similar to that described, and that the same frequency is the result. It may be here mentioned that the regularity of

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the oscillations of the third class was somewhat disturbed by the superposition of oscillations of the second class.

Penetration into the Main Magnetic Circuit of Oscillations due to the Teeth.

In all the coils on the main magnetic circuit oscillations were observed on open circuit and on all loads. They were least in the yoke, greater in the limb, and most of all in the pole shoe. The oscillations are shown in Fig. 10.

It would appear that the varying degrees of penetration were partly due to the construction of the machine in the parts affected. The yoke

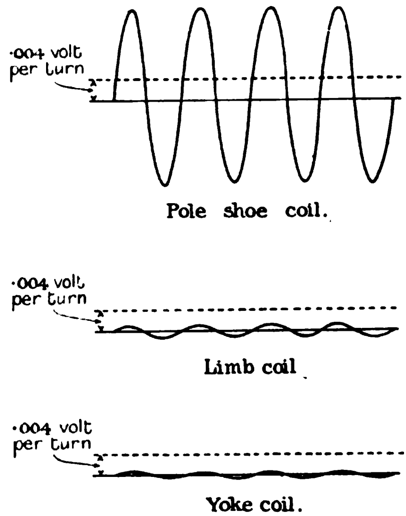

Fig. 10.—Penetration of Oscillations into Main Magnetic Circuit. Closed Slots, Open Circuit.

was solid, while the limb and pole shoe were laminated. Opposition to the oscillations would be offered in the yoke by both hysteresis and eddy currents and in the limb and pole shoe by hysteresis alone. But although this varying degree of oscillation was observed in the different parts of the circuit, their several magnitudes were nearly constant under all conditions of load and open circuit, and when the slots were open and closed. This constancy of magnitude is the more remarkable in consideration of the variation in magnitude observed in similar oscillations on the pole face, and in the interpolar space due to the teeth. The constancy would appear at first sight to be due to magnetic saturation of the iron, but that this was not the case was shown by the sensitiveness to change of exciting current of the main E.M.F.

In the part of the investigation now under consideration it was

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found necessary to guard carefully against any confusion between the cause of the oscillations in the main magnetic circuit and the cause of those which were observed on the pole face. For, while the latter, as has been described, were due to that local movement of the flux described as "flash" and "drag," the former were probably due to a variation of reluctance of the main magnetic circuit consequent upon a variation of the number of teeth under the pole face.

Thus as the causes of these two classes of oscillations are entirely apart, the existence of one class does not depend upon that of the other.

In the machine used for the present investigation the width of the pole face was equal to 5¼ times the tooth pitch, thus during the movement of the armature the maximum variation in the number of teeth at one time under the pole face amounted to that of a whole tooth, which, of course, was the greatest possible. Hence, the oscillations recorded were the maximum possible, and it would appear that if the width of the pole face had been a multiple of the pitch of the teeth the minimum magnitude of oscillations would be reached, if they did not altogether disappear.

Their magnitude in each individual part of the circuit, as has been stated, was nearly constant, but the slight variations that were observed and their cause are worthy of note here.

They were least with closed slots on open circuit and inductive load, and greatest with closed slots on non-inductive load. Their being least in the former circumstance is probably due to the bridge formed by the closing of the slot reducing the variations of reluctance of the main magnetic circuit, which, as has been previously remarked, govern the magnetic oscillations under consideration. Their being greatest in the latter circumstance is probably due to the saturation of the bridge by the local flux produced by the armature current, the current in the conductors under the pole face not being sufficient on inductive loads to produce this saturation.

Penetration into the Main Magnetic Circuit of Oscillations due to Armature Inaction.

The importance of the oscillations due to armature reaction is enhanced when it is considered that their low frequency causes them to penetrate further into the main magnetic circuit than is possible in the case of those due to the teeth, on account of the very high frequency of the latter.

Influence of Magnetic Oscillations on the P.D. Wave.

Dr. K. Simons* points out that when the number of teeth under cover of the pole face is greater or less by unity than the number of slots, the ripples in the E.M.F. wave exhibit a periodic discontinuity of phase.

As the machine used in the present investigation had the conditions

* *Electrician*, vol. lvii. page 581.

specified by Dr. Simons, the ripples referred to were, as suggested by him, exaggerated in the current wave by means of resonance, with the result that the phenomenon observed by Dr. Simons reappeared. A

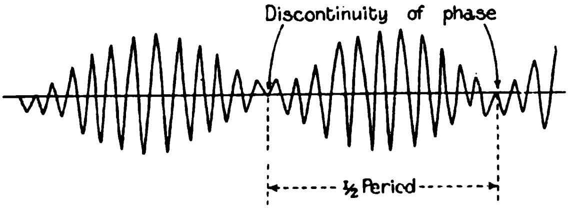

FIG. 11.—Current on Resonance for Ripples.

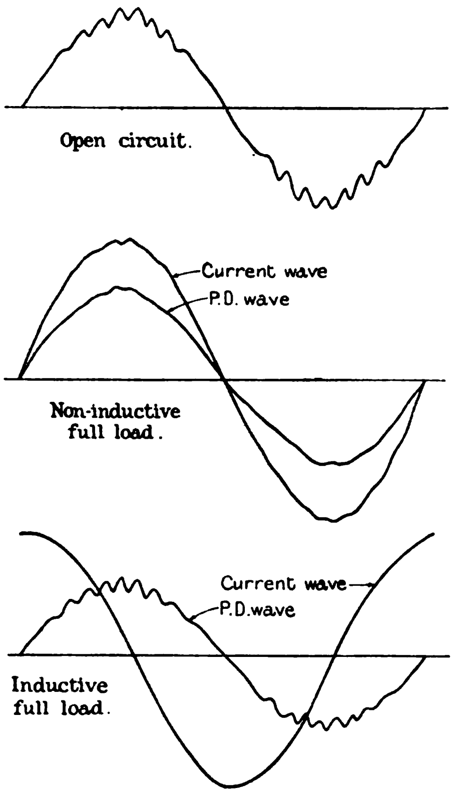

FIG. 12.—P.D. and Current Waves on Various Loads, Open Slots.

record of this will be found in Fig. 11. It will be seen from this record that the locality of the discontinuity is the neutral plane and that it occurs when the ripple is at zero value.

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The cause of the ripple being at zero value at the instant of the discontinuity of phase is that at that instant the teeth are symmetrically arranged about the pole face. And the cause of the phenomenon itself is probably the change in the direction of field relative to the conductor and the simultaneous absence of change in the phase of the oscillations.

The ripples in the P.D. wave, as will be seen by reference to Fig. 12, are less on non-inductive load, and equal on inductive load, to those on open circuit. This variation in ripple magnitude is due to the varying impedance offered to the ripple current by the load. With inductive load the impedance is far higher for the ripple current than for the main current, on account of the high frequency of the former; whereas with non-inductive loads the impedance is the same for both.

The thanks of the author are due to Messrs. F. A. Lawson, B.Eng., and W. P. Fuller, B.Eng., for their kind assistance in some of the experiments; to Messrs. Thos. Parker, Ltd., Electrical Engineers, of Wolverhampton, for their loan of plant; and to Professor Silvanus P. Thompson and Professor E. W. Marchant, for their valuable advice.

Discussion.

Mr. Cramp.

Mr. W. Cramp (*communicated*): I note that the author has obtained one or two very positive results. The first of these is the enormous difference between closed and open slots in the percentage of moving flux. So marked is this that I see no necessity even for laminated pole faces with closed slots.

The second is the difference in E.M.F. wave-form for closed and open slots, which appears to me to be what one would expect, except in one particular, viz., that there seems to be no reason whatever why the "drag" should have become quicker than the "flash"; indeed, I can hardly believe that this was the case.

I doubt if the author's explanation of the oscillations in the neutral plane is correct. What reason is there to suppose that they are not due to ordinary interpolar induction? In such a machine as that which has been examined there would be a large flux from the tips of the poles, and this would, of course, have a drag and a flash. Was the test coil in the geometrical neutral plane, or the experimental neutral plane? This explanation also will accord with all the other phenomena mentioned.

On page 214 the author explains the superimposed harmonic = three times the machine frequency. But his explanation really ought to account for an harmonic of six times the usual frequency.

Dr. Marchant.

Dr. E. W. Marchant: I feel a certain amount of diffidence in speaking on the paper, because it is not one which lends itself at all easily to adequate discussion. The subject dealt with is a difficult one to handle, and I think a great deal of credit is due to the author, in the first place for the experimental skill he has exhibited in studying the phenomena with which he has been dealing, and in the second place for the skill with which he has been able to separate the facts one from the other. The results when first obtained in the mass are exceedingly

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complicated, and to separate out the effects that are due to the various causes with which he has dealt—armature reaction, teeth, and so forth—is not at all an easy task. I think that Mr. Cramp has hit upon the one which is the most striking of all, and that is the enormous difference there is between the E.M.F. induced with open slots and with closed slots. Of course, the closed slot which has been tried is only one of many which might be taken, and naturally the magnitude of the effect would depend very largely on the size of the bridge across the top of the slot. If that bridge is fairly wide, then the oscillations at the pole face will naturally be small, whereas in a machine with a narrower bridge than that, the effect will be magnified. I think it would be interesting if the author could give us some idea as to the relative magnitudes of the E.M.F. induced in the semi-closed slots as compared with those now found in open slots. One would expect with the open slot that the magnitude of the E.M.F. induced by the pole would be considerably greater than with a semi-closed slot. My impression is that the actual magnitude of the semi-closed slot is, if anything, greater than with the open slot, due to the greater concentration of the flux at the tip of the teeth. I think the presence of the oscillation which is referred to on page 214 (the regular one), three times the frequency of the machine, is very interesting. The usual explanation, of course, of armature reaction in a 3-phase generator is that no ripple of that kind is obtained. It is extremely interesting to find experimentally that there is an oscillation in the flux of triple frequency. I am inclined to think that the author's explanation is correct, namely, that during the motion of the armature a position of symmetry with each phase occurs three times during the motion, through a distance equal to that between two north poles. Dr. Marchant.

The effect appears to depend on the type of winding. With windings having a coil for each pole or with tapped continuous-current wave winding, the frequency of the resultant flux would be six times the main frequency. With hemitropic winding, however, or within tapped continuous current lap windings the triple frequency oscillation would be expected.

Fig. 10 is an extremely interesting one, as it shows the amount of penetration into the pole. The magnitude of the oscillation at the centre of the magnet limb appears to be about $\frac{1}{12}$th of that at the pole shoe, so that even with laminated poles, which of course are the best conductors for these oscillations, the magnitude is enormously reduced in the short distance between the pole shoe and the pole limb, and, of course, when one comes to the yoke, the magnitude is still less.

Fig. 11 is also a most interesting one, as it shows the presence of the discontinuity of phase, and, as far as I know, no record of such a result has been given before.

Mr. M. B. FIELD: This is the second paper we have had from Mr. Worrall on the subiect of "Magnetic Oscillations in Alternators." It seems to me what practical men wish to know is, what effect these oscillations have, first of all upon the price or efficiency of the machine, Mr. Field.

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Mr. Field. and, secondly, apart from the machine, upon the efficiency and working of the system outside of the machine.

I do not find any indication of this in the paper at all, and I think perhaps the author is saving it for a third paper upon the subject ; but as it is very important to know whether there is any such effect, I hope he will be able to give us some information about it in his reply. If the answer is that there is no such effect of any magnitude, this in itself is a practical result of the very greatest importance and worth a good deal of trouble and experimenting to settle. But here, for the practical man, the whole matter ends. I think this is a legitimate point to raise, because the title of the paper is "Magnetic Oscillations in Alternators and their Bearing on the Design."

The paper certainly brings out a large difference between open and closed slots ; but it is, of course, well known independently of the paper that open slots are much more likely to produce heating in the pole faces due to disturbances of the magnetic flux than is the case with closed slots.

The author states that wherever else magnetic oscillations may occur they are not likely to occur in the interpolar space, and expresses some surprise at finding them there, the mere fact of the oscillations being less in the limb than in the pole shoe, and still less in the yoke (a matter described by Mr. Worrall under the heading "Penetration") clearly indicates that the oscillating magnetic lines must be leaking out into the interpolar space.

The author has explained the voltage in his neutral search coil in Fig. 6 by supposing that the magnetic lines are springing from tooth to tooth, and sometimes spring through the loop formed by the neutral search coil, but the further experiments upon the penetration clearly indicate that another cause for E.M.F. in this search coil, and perhaps more especially in the arc search coil, to be looked for. I should like to ask Mr. Worrall whether he has made any experiments with the hydrodynamic method. A good many of the results, in fact nearly all the results, on open circuit might be supplemented by this method, and a very beautiful method it is. Here we are dealing direct with the lines of force, but in the method of search coils we are dealing merely with the effect of the movement of lines relative to the search coils. The phenomena that have been recorded are the E.M.F.'s, which have to be interpreted back into movements of quantities of flux. The method is obviously indirect, but in many cases it seems that there is no help for it, as the hydrodynamic method has its limitations. The latter method, however, might be used as supplementary in the case of open-circuit investigations, the actual distribution of the lines of force being obtained in a number of successive positions of the moving teeth relative to the fixed magnet system.

Mr. Cramp has mentioned the matter of the armature reaction producing a frequency of six times the normal frequency. I thought the same thing when reading the paper, and am glad Mr. Cramp has mentioned it.

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Mr. H. W. WILSON: It appears to me that Mr. Field dealt with the most important point, at all events from a manufacturer's point of view, when he raised the question as to the difference of efficiency which there might be between an armature with closed slots and open slots. Looking at the paper broadly, it appears on the face of it as if there is something to be said for the use of an armature with closed slots, and that we should get a higher efficiency with this type. From a conversation I had with the author some time ago, I rather fancied that this was his view of the subject, and I should like him to state definitely whether there really is any appreciable advantage with the closed slot as regards efficiency. Of course, if there is any advantage in efficiency, we have to consider whether the extra cost of winding a closed slot armature is not going to do more than nullify any advantage obtained, and then, of course, there are also the other advantages and disadvantages of open slots and closed slots which have to be considered, and which might possibly do away with any slight increase of efficiency. Still this is the important part of the subject from the manufacturers' point of view. Otherwise it resolves itself into an investigation of a very interesting subject, but without any very important and immediate bearing upon the design itself. I am very much interested in Mr. Field's explanation of the weakening of the flux as it penetrates into the limb of the pole piece, and I am satisfied that what has been said accounts for the effect the author has observed, but I am not clear about the other diagram. It appears to me that Mr. Worrall and Dr. Marchant are right, and we should get a triple effect, because as the coil passes underneath both poles at the same time the effect produced would be a triple effect. There is one point that I should like the author to say something about, and that is, did he, in making the experiment, use the same magnet limbs throughout, or did he try more than one type? In the sketch the author only shows the one form of limb and the one form of pole face. Is the experimental machine fitted with any other shaped pole faces which can be exchanged so as to carry out other experiments, because it seems to me that a variation in the form of the pole face itself may make a tremendous difference in the result of the investigation? Mr. Wilson.

Mr. J. PURRETT (Salford): I should like to ask the author what he reckons would be the effect of the oscillations upon the running of alternators in parallel. It seems to me that with different types of machines we should get totally different oscillations, and therefore some effect upon the satisfactory running or otherwise. Mr. Purrett.

Mr. WORRALL (*in reply*): Mr. Cramp has remarked upon the enormous difference between open and closed slots in the percentage of flux oscillating on the pole face, and has concluded that with closed slots there is no necessity to laminate even the pole faces. I would point out that these oscillations are mainly on the surface and penetrate but a very short distance into the pole shoe, and it is just a question whether the necessity for lamination of the pole shoe arises from the oscillations in the main magnetic circuit, or from those occurring Mr. Worrall.

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Mr. Worrall.

on the pole face; the former are as large with closed as with open slots. I believe that the latter is the case, and I agree with Mr. Cramp on that point. Mr. Cramp has also remarked on the difference between the E.M.F. wave-form with the closed and open slots. I take it that Mr. Cramp means the E.M.F. wave induced in the search coils. I think that the explanation I have given of this point in the paper is reasonable, namely, that the duration of the "flash" and the "drag" together is constant; with open slots the duration of the "flash" is equal to that of the "drag," but when the slot is closed by the iron bridge the "flash" is impeded, and its duration increased, with the necessary result that the duration of the "drag" is reduced. In reply to Mr. Cramp's question as to the position of the neutral search coil, it is placed in the geometrical neutral plane. I do not agree with his suggestion that the oscillations exhibited by the coil are entirely due to interpolar induction, for if that were so, several phenomena might be expected as the result of the shifting of the experimental neutral plane, which I certainly have not observed during the investigation.

With regard to the frequency of the armature reaction oscillations, I think the difference of opinion is, as Professor Marchant has suggested, due to considering different types of winding; the armature of the experimental machine was lap wound. Referring to Professor Marchant's question about the relative values of the E.M.F.'s induced in the search coils of the previous investigation with semi-closed slots, and those of the present one with open slots, the E.M.F. per conductor of the search coils in the former case was of the order of 0·25 volt, while in the present case it is about 1 volt.

I have not tried the hydrodynamical method of investigation as that method, although of great value in certain cases, can only be used with a stationary armature and field, and therefore not under the actual running conditions when hysteresis is a very important factor even on open circuit.

In reply to Mr. Purrett as to the influence of the magnetic oscillations investigated on alternators in parallel, the only point to be considered is the shape of the E.M.F. wave, for if the teeth are few and large, the wave will be peaked, and thus interfere with successful running in parallel.

I have since experimented upon both lap- and wave-wound machines in the laboratories of Liverpool University, and, through the courtesy of the Liverpool Education Committee, in the Central Technical School. A coil of about twenty turns was wound round a pole shoe of each machine, and the oscillations occurring in it were observed on the oscillograph. The lap-wound machines in all cases gave a triple frequency oscillation, while the wave-wound gave only a very slight higher frequency oscillation which appeared to be about sextuple. It was interesting to note that in all the machines experimented upon an unbalanced load produced a strong double frequency oscillation.

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ORIGINAL COMMUNICATION.

ON A METHOD OF PLOTTING THE HYSTERESIS LOOP FOR IRON WITH AN APPLICATION TO A TRANSFORMER.

By DR. GISBERT KAPP, Vice-President.

Let ϕ_o be the flux in megalines produced by a continuous current of I_o amperes through n turns of winding under an E.M.F. of e volts, then—

$$e = \mathrm{R}\,\mathrm{I}_o.$$

If now e be suddenly reversed, then I will pass from its initial value $-\mathrm{I}_o$ through zero to the final value $+\mathrm{I}_o$. Any intermediate value of the current must obviously satisfy the equation—

$$e = \frac{n}{100}\frac{d\phi}{dt} + \mathrm{R}\,\mathrm{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

By observing t and I a time-current curve may be plotted, and from this curve and the known values of e and n the hysteresis loop giving ϕ as a function of I may be drawn. The arrangement of the test is shown in Fig. 1.

B is a source of current capable of giving from 50 to 100 times the magnetising current I_o, which is passed through the transformer coil T. This current is taken off on the heavy shunt resistance S between whose terminals the E.M.F. e is maintained and indicated on the voltmeter V. A is an amperemeter with central zero and s a reversing switch. Care must be taken to have the contacts of this switch in good order, so that its resistance may be exactly the same in either position. S may conveniently be the shunt belonging to V, so that this is instrumental in indicating the main current given by B. All connections should be of sufficiently stout wire, and A should be of sufficiently low resistance to reduce the loss of E.M.F. between S and T as much as possible.

To make the test, regulate r so that A indicates the desired magnetising current I_o and note the E.M.F. e. Then knock s sharply over, starting at the same time a stop-watch and noting the current indicated by A as a function of the time. The movement of the needle for values of I lying between $-\mathrm{I}_o$ and zero is fairly quick, so that in this region single observations can only be taken by stopping the watch at the

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moment that the pointer passes a predetermined point on the scale. After the zero has been passed the movement becomes sufficiently slow for a continuous series of co-ordinate values of current and time

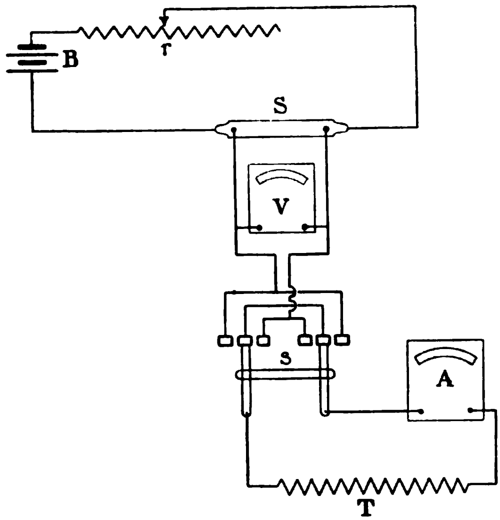

FIG. 1.

to be noted. For transformers of similar type the speed of the needle is approximately proportional to the $\frac{2}{3}$ power of the output. Thus, if

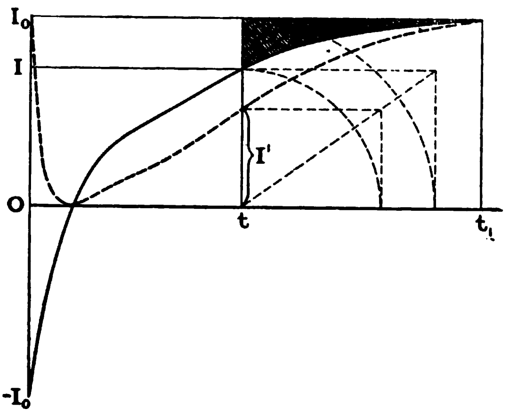

FIG. 2.

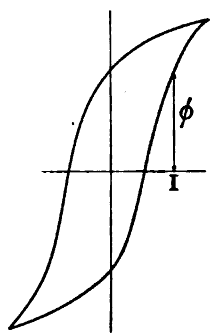

FIG. 3.

with a 10-k.w. transformer zero is reached in 4 seconds, it would be reached in about $6\frac{1}{3}$ seconds with a 20-k.w. and in about 16 seconds with an 80-k.w. transformer. The shape of the time-current curve is of the

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character shown in Fig. 2. If there were no hysteresis loss, it would be a true logarithmic curve, but owing to the influence of hysteresis there is a depression in the upper part as shown.

From (1) we have—

$$\frac{100}{n}(e - \mathrm{R\,I}) = \frac{d\phi}{dt}$$

$$\frac{100\,\mathrm{R}}{n}(\mathrm{I}_o\,dt - \mathrm{I}\,dt) = d\phi$$

$$\frac{100\,\mathrm{R}}{n}(\mathrm{I}_o - \mathrm{I})\,dt = d\phi.$$

Now $\mathrm{I}_o - \mathrm{I}$ is the length of the ordinate between the curve and the $+\mathrm{I}_o$ line, so that $\int(\mathrm{I}_o - \mathrm{I})\,dt$ is the area enclosed between the curve and this line. Integrating between the limits $-\phi_o$ and $+\phi_o$, to which correspond the times 0 and t_1, we find—

$$2\,\phi_o = \frac{100\,\mathrm{R}}{n}\,\mathrm{Q}_o \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

if by Q_o we devote the whole area between the curve and its asymptote.

Integrating between the limits $-\phi_o$ and $+\phi$, to which correspond the times 0 and t, we find—

$$\phi_o + \phi = \frac{100\,\mathrm{R}}{n}(\mathrm{Q}_o - \mathrm{Q}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

By combining (2) and (3) we get—

$$\phi = \frac{100\,\mathrm{R}}{n}\left(\frac{\mathrm{Q}_o}{2} - \mathrm{Q}\right),$$

$$\phi = \frac{100\,e}{n\,\mathrm{I}_o}\left(\frac{\mathrm{Q}_o}{2} - \mathrm{Q}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Q is the shaded area in Fig. 2. Having fixed on a value of I, we find by planimeter the corresponding area Q, and from (4) the corresponding value of the flux ϕ.

It is thus easy to find by means of a planimeter corresponding values of I and ϕ, and to plot these as shown in Fig. 3. The hysteretic energy per cycle is obviously—

$$\mathrm{E} = \frac{n}{100} \times \text{area of loop}.$$

If there are no joints in the carcase, and its cross-sectional dimensions are such as to make the induction the same in any part, the true B-H loop can, of course, be plotted, and the permeability as a function of the induction may also be found. In most cases, however, a knowledge of the exact shape of the B-H loop and of the permeability is of

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secondary importance; what we require is a knowledge of the hysteretic loss in the whole transformer, and this may be found graphically from Fig. 2 without even drawing Fig. 3.

The hysteretic energy absorbed by the carcase in one half-cycle is obviously the difference between

$$e \int_0^{t_1} \mathrm{I}\, d\, t,$$

the total energy supplied, and

$$\mathrm{R} \int_0^{t_1} \mathrm{I}^2\, d\, t,$$

the energy lost in copper heat. The latter quantity may be expressed in the form—

$$\mathrm{R\,I}_0 \int_0^{t_1} \mathrm{I} \frac{\mathrm{I}}{\mathrm{I}_0}\, d\, t \text{ or } e \int_0^{t_1} \mathrm{I}'\, d\, t,$$

where $\mathrm{I}' = \mathrm{I} \frac{\mathrm{I}}{\mathrm{I}_0}$ can be determined graphically by the construction shown by dotted lines in Fig. 2. The hysteretic energy for one half-cycle is, therefore—

$$\frac{\mathrm{E}}{2} = e \int_0^{t_1} (\mathrm{I} - \mathrm{I}')\, d\, t \text{ watt-seconds.}$$

The integral is the area (expressed in coulombs) between the original time-current curve and the new I′ curve shown in a dotted line. The area is to be taken with reference to the sign of the current; that is to say, negative up to the point $\mathrm{I} = o$ and positive for $\mathrm{I} > o$. By planimetering the two areas and deducting that which is negative, we find—

$$\mathrm{Q}_h = \int_0^{t_1} (\mathrm{I} - \mathrm{I}')\, d\, t,$$

$$\mathrm{E} = 2_1\, e\, \mathrm{Q}_h.$$

This construction applies to any transformer, whether it has joints or not, and whether the induction is the same throughout the magnetic path or not.

By way of illustration I give in Fig. 4 one of the time-current curves taken on a Westinghouse transformer of the shell type. The cross-sectional area of magnetic circuits is, in this case, constant throughout the path, namely, 200 sq. cm., its length is 53·8 cm., and as there are no butt joints (the carcase is built up with overlapping plates) it was possible in this case to find the true shape of the hysteretic loop. This is drawn to the right of the time-current curve. In the test to which Fig. 4 refers n was 120, $\mathrm{R} = 0{\cdot}1$, $e = 0{\cdot}06$, $\mathrm{I}_0 = 0{\cdot}6$.

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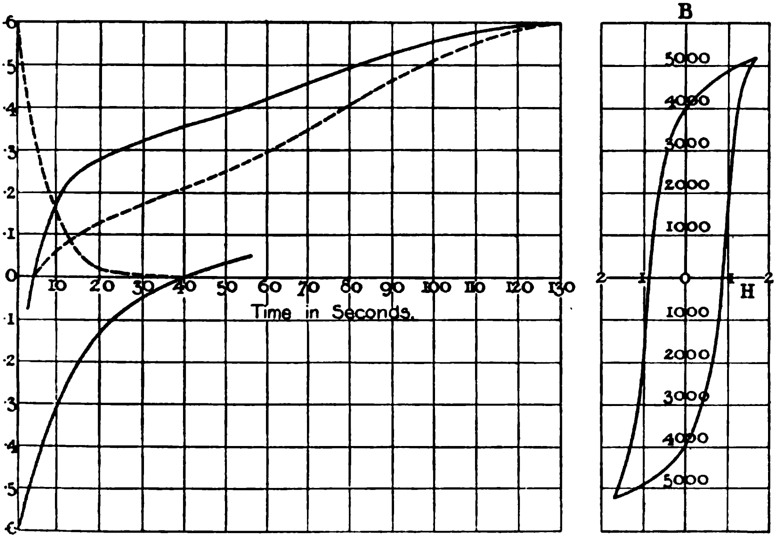

FIG. 4.

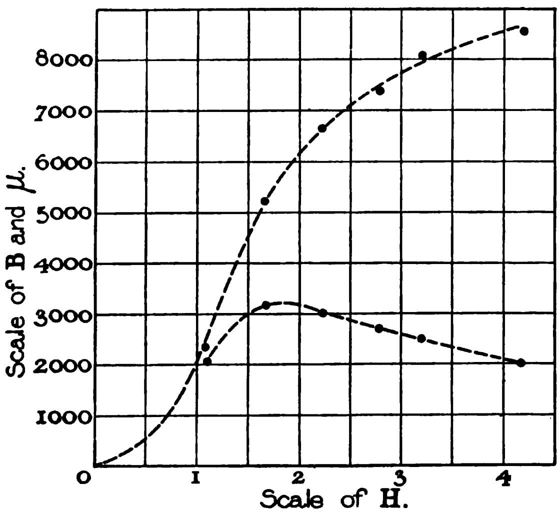

FIG. 5.

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To obtain greater accuracy in the planimetric measurements, the I and I′ curves up to zero are drawn to a time scale magnified tenfold. Tests were also made with values of I_0 ranging from 0·4 to 1·5 A

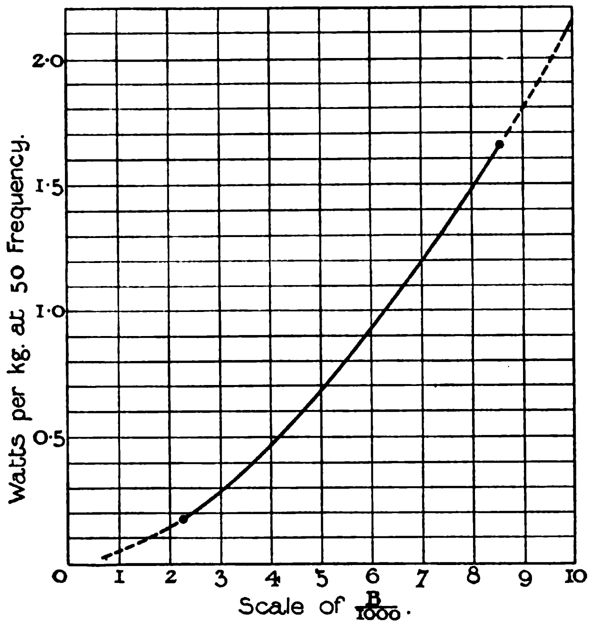

FIG. 6.

corresponding to values of B from 2,300 to 8,600 respectively. From these tests the conjugate values of H, B, and μ are plotted in Fig. 5, whilst Fig. 6 gives the curve of hysteretic loss per kilogramme of iron at 50 ∿.

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WIRING RULES.

CONTENTS.

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The standing Committee appointed by the Council of the Institution of Electrical Engineers to revise the Wiring Rules is constituted as follows, including representatives of the Municipal Electrical Association, the Electrical Contractors' Association, and of some of the principal Fire Offices.

WIRING RULES COMMITTEE.

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Acknowledgments are due to the Cable Makers' Association and the Engineering Standards Committee for their co-operation and assistance in the work of revision.

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WIRING RULES.

1. These Rules embody the requirements and precautions which the Institution of Electrical Engineers has framed to secure satisfactory results with a supply of electrical energy at low pressures, not exceeding 250 volts. They are intended to include only such requirements and precautions as are generally necessary, but they are intended neither to take the place of a detailed specification, nor to instruct untrained persons.

For medium pressures exceeding 250 volts but not exceeding 650 volts, the additional requirements and precautions are contained in the Board of Trade Regulations which are set out on pages 25, 26, as far as they relate to conditions similar to those intended to be covered by these Rules. The Home Office Special Rules for the Installation and Use of Electricity in Mines are set out on pages 27 to 38.

2. Notice of the introduction of wiring should in all cases be given to the Fire Offices insuring the risk, and their suggestions respecting any details not covered by these Rules or any deviations arising from special conditions should be adopted. When the supply is to be obtained from an external source, notice should be given to the suppliers before wiring. Fire Offices.

DEFINITIONS OF CERTAIN TERMS USED IN THESE RULES.

3. *Three-wire System.*—A three-wire system is one in which three conductors are maintained at different potentials, the conductor at a potential intermediate between the highest and lowest being common to all lamps or other consuming devices supplied on either side of the system.

4. *Neutral Conductor.*—The neutral conductor of a three-wire system is the conductor which is at a potential intermediate between the potentials of the outer conductors.

5. *Outer Conductor.*—The outer conductors of a three-wire system are those between which there is the greatest difference of potential.

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Note.—This specialised use of the word "outer" must not be confused with the non-technical use of the word when applied to the external conductor of a concentric main which physically surrounds the other conductor or conductors of such main.

6. *Earthed Conductor.*—A conductor is said to be earthed when it is connected to the general mass of the earth in such a manner as will ensure at all times an immediate and safe discharge of electrical energy.

7. *Uninsulated Conductor.*—A conductor is said to be uninsulated when, although not earthed, no provision is made by the interposition of a dielectric or otherwise for its insulation from earth.

8. *Bunching of Conductors.*—Conductors are said to be bunched when more than one is contained within a single duct or groove.

9. *Single-pole Switches.*—Single-pole switches are switches interrupting one conductor only of a circuit.

10. *Linked Switches.*—Linked switches are single-pole switches fixed on conductors of different polarity linked together mechanically so as to operate simultaneously.

11. *Dielectric.*—A dielectric is any material which by its nature or the method of its application to a conductor permanently offers high resistance to the passage of current and of disruptive discharge through itself.

12. *Grade of Insulation.*—A cable is said to be of I.E.E. 600 or 2,500 megohm grade when its minimum insulation is that shown in cols. 5 and 6, respectively, of the Table when tested at 60° F. (15·6° C.) after one minute's electrification and 24 hours' immersion in water.

13. *Ventilated Motors.*—A ventilated motor is one in which, while ventilation is provided for, access to the armature, field coils, and other live parts is only to be obtained by opening a door in, or removing a part of, the enclosing case.

14. *Totally Enclosed Motors.*—A totally enclosed motor is one in which all the live parts, whether insulated or not, are totally enclosed, as in paragraph 13, but without provision for internal ventilation.

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LOW PRESSURES NOT EXCEEDING 250 VOLTS.

GENERAL ARRANGEMENT.

15. Every system must be protected by linked main switches or linked switch-fuses under the control of the consumer, and these must be easily accessible and placed as near the generator or the entry of supply as circumstances permit. **Control.**

16. When one of the main conductors of a system of supply is earthed, no interruption of the current is permitted in a conductor connected to the earthed main, unless a simultaneous break is effected on the non-earthed conductor. Hence, to ensure the current being interrupted simultaneously on both the earthed and the non-earthed wires, no switch or switch-fuse that is not linked to another switch or switch-fuse on the non-earthed conductor may be inserted in any conductor connected to an earthed main. **Interruption of Current.**

17. No fuse may be placed in the neutral conductor of a three-wire or other multiple-wire system, but fuses must be placed on both conductors of two-wire circuits branching therefrom. This does not prevent the use of a disconnecting link in the neutral conductor for testing purposes. **Fuses in Multiple-wire Systems.**

18. When the wiring is such that one conductor is uninsulated at all points—such as a bare return to a concentric system—no switch or fuse may be placed in that conductor, and the said conductor must be efficiently earthed. **Uninsulated Returns.**

19. When the pressure between the outer conductors of a three-wire system exceeds 250 volts and the three wires of the system or two pairs of wires are brought into premises, the supply shall be given to two pairs of terminals arranged so as to minimise the danger of shock, and the wiring from these terminals shall be kept distinct throughout, and so arranged that a person cannot simultaneously touch two points respectively in contact with the outer conductors. In the case of other multiple-wire systems similar principles shall be applied. **Introduction of Multiple-wire System into Premises.**

20. When energy is taken from all the conductors of a two-phase or three-phase system, the conductors must be protected, either by an automatic triple-pole circuit-breaker, or by a fuse on each pole in conjunction with a triple-linked switch; or by three switch fuses. **Protection in Polyphase Systems.**

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Current in Circuits and Sub-circuits.

21. Conductors must radiate from distributing centres, and in large systems from those centres to sub-centres, so that no final sub-circuit carries more than 5 amperes up to 125 volts, or more than 3 amperes from 125 to 250 volts, for incandescent lighting. The sub-circuits for small heaters must not carry more than 15 amperes up to 125 volts, or more than 10 amperes from 125 to 250 volts, and they must be protected by a fuse on each pole. Heaters and apparatus exceeding the 10-ampere limit must comply with paragraph 91 (*e*) (1) and (2).

Fuses in Sub-circuits.

22. Every sub-circuit must be protected on each pole by a fuse (par. 18).

Bunching.

23. When protected from mechanical injury by metal tubes or conduits (par. 46 (*a*)), conductors of opposite polarity may be bunched, and when carrying small currents for incandescent lighting, from sub-centres, as in paragraph 21, they may also, if without joints, be bunched when the protecting tubing or casing is non-metallic. If the supply is alternating and the protection metallic, the lead and return conductors must be bunched.

Earthing.

24. Where metallic sheathing or tubing is used it must be electrically and mechanically continuous and connected to earth. The conductor (earth-wire) used for the purpose of earthing must be of copper and of a sectional area not less than that of No. 14 S.W.G.

Gas-pipes.

25. There must be no contact between conductors (or their insulating material, metallic sheathing or tubing) and gas pipes. Non-conducting distance-pieces must be used where necessary.

Gas-pipes.

26. Gas-pipes must never be used to obtain an earth connection.

Concentric Wiring.

27. Where concentric wiring with an uninsulated external conductor is used, this system of wiring must be employed throughout, except for fittings and pendant flexibles.

Earthing in Concentric Wiring.

28. When the mains are earthed at one point, the external conductor of a concentric system is the conductor to be connected to the earthed main.

Inflammable Gases and Dust.

29. In places where inflammable or explosive dust, gases, or vapours are liable to be present, dynamos, arc lamps, Nernst lamps, and connectors must not be used. In such situations, incandescent lamps must, with their holders, be enclosed in air-tight fittings of thick glass; switches, fuses and resistances must be enclosed in gas-tight boxes or break under oil; and motors, with their live parts, starters, terminals and connections, must be completely enclosed (par. 91 (*d*)) in flame-tight enclosures made of uninflammable material.

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30. Except where completely enclosed in a metallic casing, no switch, ceiling-rose, cut-out, connector, or other electrical accessory, may be mounted directly upon any surface of a condensing or humid nature, such as masonry or brickwork, but must, in addition to its own mount, be fixed upon a base block rendered impervious to moisture. Damp Surfaces

CONDUCTORS—SIZE AND CONDUCTIVITY.

31. Excepting for wiring fittings, the sectional area (see Table) of any copper conductor must not be less than that of No. 18 S.W.G. It must be assumed that, at least, 60 watts may be consumed at any point (par. 97). Size.

32. The size of conductors within a building will, subject to paragraphs 31 and 35, be determined by the permissible drop in volts, which should not exceed 2 per cent. on lighting circuits. Size.

33. Covered copper conductors should be of soft copper, and should have a conductivity not less than that of the E.S.C. standard (par. 113); where sulphur compounds are present in any part of the insulating material the copper in contact with the insulating material must be protected therefrom by tinning or otherwise. Conductivity. Sulphur.

34. All covered copper conductors having a greater area than that of a No. 14 S.W.G. wire must be stranded. Stranding.

35. The Table appended shows the sizes of copper conductors which will safely carry currents up to 750 amperes, and the length in yards of single conductor in circuit for each volt of fall of potential when the maximum continuous current is in use. Table

CONDUCTORS—INSULATION.

36. Conductors, except as provided in paragraph 52, must be specially insulated with material which does not deteriorate at the highest temperature to which it will be subjected; for instance, rubber must not be allowed to exceed 130° F. (54·4° C.), and paper or fibre must not be allowed to exceed 176° F. (80° C.) Temperature.

37. The insulating material on any conductor other than a flexible must be throughout either—

A. A dielectric, such as vulcanised rubber of the best quality, which is impervious to moisture and only needs mechanical protection (par. 46). ("Dielectric" does not include braiding or taping.) Or Vulcanised Rubber.

B. A dielectric, such as paper or fibre, which must be kept perfectly dry, and therefore needs to be encased Paper and Fibre.

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in a waterproof sheath, generally of soft metal, such as lead, drawn closely over the dielectric.

Thickness. 38. The radial thickness of vulcanised rubber must be not less than that given in Columns 9 and 10 of the Table, or in proportion thereto. The radial thickness of dielectrics of Class B must be not less than that given in Column 11 of the Table. The dielectric must not soften sufficiently to allow decentralisation at a lower temperature than 176° Fahr. (80° C.)

Tests. 39. The dielectric must be such that when the insulated conductor has been immersed in water for twenty-four hours it will, while still immersed, withstand 2,000 volts for half an hour between the conductors or between the conductor and the water, the test pressure being applied with alternating current at a frequency of 50, the E.M.F. curve being as nearly as possible a sine-wave.

Insulation Resistance. 40. The minimum insulation resistance should be that given in Columns 5 and 6 of the Table for vulcanised rubber, and that in Column 7 for Class B, the test being made at 60° F. (15·6° C.) after one minute's electrification at 500 volts, and after the insulated conductor has been immersed in water for the twenty-four hours immediately preceding the test.

Twin Conductors. 41. The insulation resistance between the members of twin-conductors should be not lower than the corresponding insulation resistances in the Table.

Taping and Braiding. 42. Conductors insulated as in Class A must be taped and braided if drawn into conduits, and at least taped if laid in casing.

Concentric Conductors. 43. Concentric conductors (pars. 18, 27, and 28) should in all respects conform to the requirements laid down for single conductors; the insulation resistance of the dielectric separating the two conductors must be that given in the Table for single conductors having the same diameter as the inner conductor. The insulation resistance of the dielectric on the external conductor, where insulated, must be that given in the Table for single conductors having the same diameter as the outside diameter of the external conductor.

CONDUCTORS—FLEXIBLE.

Size. 44. Flexibles must be of a sectional area not less than that equivalent to No. 22 S.W.G.,[1] and they must be made up of wires twisted together on a short lay, the sectional area of each wire being not greater than that of No. 36 S.W.G. The insu-

[1] The following have a sectional area equivalent to No. 22 S.W.G.: 34/40 22/38, 14/36.

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lating material used as the dielectric must be pure rubber equal to washed Para rubber of the best quality or vulcanised rubber of the best quality. Pure rubber insulation is best suited for flexibles intended for use with pendants. Pure rubber must be laid on in two layers, care being taken that each layer overlaps, and the radial thickness of the dielectric must not be less than 20 mils. Each coil of pure rubber flexible must be tested for 15 minutes with a pressure of 1,500 volts alternating between the conductors at a frequency of 50. Vulcanised rubber flexible must be insulated with one layer of pure rubber and two layers of vulcanised rubber, and the radial thickness of the dielectric must not be less than 34 mils. Each coil of vulcanised rubber flexible must be tested for 15 minutes with a pressure of 1,500 volts alternating at a frequency of 50, after twenty-four hours' immersion in water and while still immersed. When sulphur is present, the insulating material must not be in direct contact with the copper wires. Dielectric. Tests and Thickness of Dielectric. Sulphur.

45. Flexibles (pars. 25, 51, 75 and 76) may be used only for attaching to pendant or portable appliances, or for sub-circuits under the conditions of paragraph 46 (*c*). They must not be used in any position out of sight, except where passing directly through walls, when they must be protected by incombustible watertight conduits. They must not pass through floors. The connection between flexibles and hard wires may only be effected by means of screw-down terminals in junction boxes or ceiling roses, and where flexibles from fittings must pass into a ceiling they must be enclosed in conduits up to a metal junction box. Where Permitted. Connections.

CONDUCTORS—FIXING AND SUPPORTING.

46. Conductors (excepting flexibles) insulated as in Classes A and B (par. 37) :—

(*a*) May be enclosed in steel conduits with details and accessories complying with the British Standard Specification for "Steel Conduits for Electrical Wiring" or in brass or copper conduits ; but all conduit systems must be electrically and mechanically continuous throughout, have all outlets bushed to prevent abrasion, and be connected to earth (pars. 25 and 26). In dry places isolated single lengths of tubing need not be earthed if adequately enamelled, or otherwise insulated, externally. In damp places the conduit system must be watertight. Conduits Steel Conduits.

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must be efficiently drained if liable to internal condensation. Sharp bends or elbows are prohibited, but inspection elbows are permissible.

Wood Casing.

(*b*) May be enclosed in wood casing in dry places where not buried in plaster or cement nor exposed to moisture. Unless efficiently protected from drip, wood casing must not be fixed immediately below, and in no case must touch, water pipes. Conductors carrying more than 5 amperes must be laid singly in separate grooves.

Conductors without Mechanical Protection.

(*c*) May be without mechanical protection (*i.e.*, without conduit, armouring, etc.) where not exposed to injury, but they must be supported in such a manner as to secure the permanent spacing of the conductors from walls, ceilings, and all structural metal work and metal piping. When carrying more than 5 amperes they must also be spaced from each other, unless they are of the multiple-core or concentric types. Such spacing is not, however, necessary if the conductors are lead-covered (par 25).

Lead-covered Conductors.

47. Unenclosed lead-covered conductors must be supported on a continuous wood fillet, or fastened by broad clips, which, in damp places, must be of lead.

Floors and Walls.

48. Conductors where exposed to injury (*e.g.*, where passing out of floors), must be specially protected by stout conduits or boxing, and where passing through walls, partitions, or ceilings, they must be enclosed in porcelain or other protecting conduits.

Party Walls and Floors.

49. Conductors passing through party walls or fire-resisting floors must be provided with special protection, such as a close-fitting porcelain or other incombustible tube, to prevent the spread of fire through the openings. When the end of the tube is outside the building, it should be bell-mouthed or bushed, and turned downwards.

Rain.

Plaster.

50. Conductors buried in plaster must be provided with mechanical protection.

Staples.

51. Metal staples must not be used for fixing unarmoured conductors.

CONDUCTORS—BARE.

52. Bare conductors without any insulating covering may be used indoors—

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(*a*) As collector wires for travelling cranes and similar appliances, but they must be so supported upon insulators as to prevent contact between the conductors themselves, or between the conductors and the walls or the structural or other metal work, should a collector wire be displaced from any insulator. The insulation at each straining point (*i.e.*, at the end of each wire) must consist of two strain insulators placed in series. The current must be under complete control by means of a switch and a fuse, or a switch-fuse, in each supply conductor. Lightning arresters must be fitted if the bare wiring extends to an exposed position in the open. Travelling Cranes.

(*b*) As trolley wires for locomotives, jib cranes, and similar appliances, but they must be insulated by means of two strain insulators placed in series between each wire and "earth" at their points of support. Wall rosettes or brackets used as supports for span wires should not be fixed within one foot of any gas pipe. Controlling switches and fuses, or switch-fuses, and lightning arresters must be provided as under (*a*). Locomotives, Jib Cranes.

(*c*) As battery connections, but such conductors must be well spaced from each other and from all structural or other metal work, and be rigidly supported on insulators. Batteries.

(*d*) For other purposes, under special circumstances and in positions inaccessible to unauthorised persons, but permission for such use should be previously obtained from the Fire Offices insuring the risk. Power Purposes.

JOINTS AND CONNECTIONS.

53. Joints constitute a source of weakness and should be avoided whenever possible.

54. Joints, when unavoidable, must be accessible, and they must be mechanically and electrically perfect to prevent heat being generated. All joints must be soldered. Soldering fluids containing acid, or other corrosive substances, must not be used.

When junction-boxes are used they must be so constructed that— Junction Boxes.

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(*a*) the conductors cannot be readily short-circuited;
(*b*) the insulation between opposite poles is rigid and durable;
(*c*) the connections do not heat;
(*d*) if used in damp places, moisture is excluded by suitable means.

Jointing Conductors. 55. In jointing conductors the braid, tape or lead, must be carefully removed without damage to the dielectric and for a sufficient length to ensure a thorough union between the dielectric and the material used to insulate the joint. If the insulating material is not waterproof, it must be covered with an impervious sleeve or box, which must make a water-tight joint on each side of the junction. Care must be taken to exclude moisture during the operation.

Looping. 56. Looping should be employed to avoid joints on small conductors.

Connections at Terminals. 57. Where conductors are connected to switches, fuses, junction-boxes, or other appliances, the whole of the separate wires forming the stranded or flexible conductor must be contained within the terminal. The dielectric must not be bared back further than to allow the conductor to enter the terminals properly, and the ends of the insulation Class B should be sealed

Moisture at Terminals. 58. With dielectrics of Class B, the exposed ends of conductors, where they enter the terminals of switches, fuses, and other appliances, must be protected from moisture which might creep along the insulating material within the waterproof sheath.

Water-proofing at Terminals. 59. Where conductors enter the terminals of switches, fuses, and other appliances, the braid, lead, or other covering must be cut back from the end of the dielectric, which must be waterproofed. In damp places the strands of conductors of Class B should be soldered to prevent moisture creeping along the copper beneath the insulating material.

Soldering to Lugs. 60. Conductors of larger sectional area than that of 7/18 S.W.G. must be soldered to proper lugs for connection. Where there is any possibility of stress on the lugs the conductors must be secured, in addition to the soldering, by some mechanical device, such as one or more grub-screws.

SWITCH AND DISTRIBUTION BOARDS.

Position and Construction. 61. Main and distribution switch and fuse boards must be fixed in a dry situation, and be so arranged that a fire thereon

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cannot spread, whether occurring at the front or back. Their bases must be of incombustible and insulating material, with moisture-proof bushes fitted at the points of support if the material is hygroscopic. The possibility of a permanent arc must be prevented either by sufficient spacing of all live parts, or by the use of separating partitions.

62. Connections at the back of main boards must be accessible, symmetrically placed, and spaced apart, and, unless protected from acid fumes, must not project into battery rooms. Accessibility

63. Switchboard circuits should be labelled for identification. Labels.

64. No open-type fuses may be placed at the back of switchboards. Fuses.

65. The cases of instruments, if metallic, must be insulated from the circuits. Metal Cases.

66. Every voltmeter or pilot lamp with its connecting wires should be protected by a fuse on each pole. Fuses.

67. Combination switch and fuse boxes must be so arranged that it is possible to operate a switch without uncovering the fuses, if of the open type. Combination Boxes.

68. When fuses are of the open type and grouped together, the case of the distribution board will be a sufficient protection from the fused metal provided the distance from cover to fuse exceeds one inch with glass-fronted cases. If made of wood, the case must be protected with fire-resisting material, and a clearance of one and a half inches should be provided. Fused Metal.

SWITCHES.

69. Switches (pars. 29 and 30), whether fixed separately or combined with lampholders or fittings, must comply with the following requirements :—

(*a*) Overheating must not take place at the point of contact or elsewhere, when the full current flows continuously. Overheating.

(*b*) They must be incapable of forming a permanent arc when breaking circuit. Switches should be tested with pressures and currents 50 per cent. in excess of those which will be used on the circuits for which they are intended. Size.

(*c*) The bases must be of incombustible non-conducting and moisture-proof material. Bases.

(*d*) Unless placed in an engine-room or in a compartment specially arranged for the purpose, switches must have their live parts covered. The covers Covers.

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must be of incombustible material, and must be either non-conducting, or of rigid metal, and clear of all internal mechanism. For more than 5 amperes, at pressures over 125 volts, metal covers must be lined with insulating material.

Boxes. (*e*) Switches in positions liable to injury, or contact with goods, should be further protected by an open-fronted box or other suitable guard.

Handles. (*f*) Handles must be insulated and so arranged that the hand cannot touch live metal, or be injured through an adjacent fuse blowing.

FUSES.

70. Fuses (pars. 29, 30, and 68) must comply with the following requirements :—

Over-heating. (*a*) No overheating of any part must take place when the full current flows continuously.

Size. (*b*) They shall effectually interrupt the current when a short-circuit occurs, and also when the current through them exceeds the working rate by 200 per cent., the current flowing under the normal pressure, but they must be so proportioned to the current to be carried that no conductor protected by them can be raised in temperature above that specified in paragraph 36.

Terminals. (*c*) The terminals must be so spaced apart or screened that an arc cannot be maintained when the fuse is blown.

Bases. (*d*) The bases must be of incombustible, non-conducting, and moisture-proof material.

Covers. (*e*) Unless placed in an engine-room or in a compartment specially arranged for the purpose, fuses must have covers to retain the fused metal. The covers must be of incombustible material, and must either be non-conducting or of rigid metal lined with insulating incombustible material, and clear of all live parts. Small, close-fitting covers should be perforated for ventilation.

Wall Sockets, etc. (*f*) Fuses must not be placed in wall-sockets, ceiling roses, lampholders, or connectors.

Pressures over 125 Volts. (*g*) Separate single fuses, and not double-pole fuses, must be used on circuits where the pressure exceeds 125 volts.

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71. Branch fuses must be grouped together in accessible positions in sight, and should be symmetrically placed and labelled for each circuit. **Branch Fuses.**

72. *Note.*—Hard metal is recommended for fuses. Soft metal fuses should be soldered to hard metal contact pieces. As a practical guide, fuses may be considered too large if they are not perceptibly warm to the touch when carrying full load, and too small if they hiss when moistened. Precautions against shock must be taken when applying this test.

CONNECTORS.

73. Connectors (pars. 29 and 30) must be capable of withstanding a test with pressure and current 50 per cent. in excess of those for which they are intended. Fixed connectors must have incombustible bases, and in damp places special watertight connectors must be used. Where the fixed part of a connector is attached to a floor it must be so arranged that no dust or water can accumulate, that all contacts are well below the floor-level, and that any possibility of danger from contact of live metal with carpets is avoided. Provision should be made to facilitate inspection. **Construction and Fixing.**

74. Connectors must be constructed so that they cannot be readily short-circuited. Clearances should be such that an arc cannot be started if the connector is pulled out while the current is flowing.

75. Flexibles for portable fittings must end in a connector.

76. Every connector, or group of connectors, must be independently controlled by a switch on the live side of the connector. To avoid leaving the flexibles live, it is preferable that the portable fittings themselves should not be provided with switches. **Switches.**

CEILING ROSES.

77. Ceiling roses (par. 30) must comply with the following requirements :—

(*a*) The bases must be of incombustible, non-conducting and moisture-proof material ; **Bases.**

(*b*) The covers must be of incombustible material, and must be either non-conducting, or of rigid metal clear of all live parts ; **Covers.**

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Terminals. (c) The terminals must be relieved of the direct pull of the attached conductor and fitting, and be so arranged that no short circuit can take place;

Flexibles. (d) They must not be used for attachment to more than two pairs of flexibles, unless specially designed for multiple pendants.

FITTINGS FOR SUPPORTING LAMPS.

Tubes and Channels. 78. Wherever brackets, electroliers, or standards require to have the conductors threaded through tubes or channels formed in the metal work, these must be of ample size and have no sharp angles or projecting edges, which would be liable to damage the insulating material, and the open ends should, where possible, be bushed.

Joints. 79. Where possible, the conductors should be carried without joints through the fittings to the lamps; but where connections at the fitting are unavoidable, special care must be taken to make the joints equal in conductivity and insulation to the rest of the work (par. 45).

Gas-fittings. 80. Combined gas and electric fittings must not be used.

81. If disused gas-fittings are adapted for electric light,

Gas-pipes. they must be entirely disconnected from the gas-pipes.

LAMPHOLDERS.

82. Lampholders (pars. 29 and 86) must—

(a) be incombustible;

(b) be specially designed if for currents above 1½ amperes;

(c) not be hung from flexibles exposed to the weather;

(d) not contain a switch if for pressures above 250 volts.

Wall Switches. 83. Switch lampholders must be controlled, preferably in groups of not more than ten, by a wall-switch.

ARC LAMPS.

84. Arc lamps (par. 29) must—

(a) be guarded by lanterns or globes arranged to intercept falling particles of carbon;

Globes and Guards. *Note.*—Lanterns or globes may be dispensed with where an open arc is essential, as in photography, and where no combustible material is present, as in a foundry; but the flooring im-

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mediately under the lamp, if of a combustible nature, must be protected from falling particles of carbon. Open inverted arc lamps, in the presence of combustible matter, must have metal reflectors rigidly attached beneath the arc, which at all times must be below the level of the upper edge of the reflector. The reflector must project at least 15 inches measured horizontally beyond the arc on all sides.

(*b*) be insulated from their support;

(*c*) be fixed so that their cases cannot come into contact with any metallic object;

(*d*) have their leading-in wires protected from rain;

(*e*) be controlled by linked switches and protected by a fuse on each pole.

INCANDESCENT LAMPS.

85. Incandescent lamps must—

(*a*) Not be placed in close proximity to combustible materials unless specially protected; shades made of combustible materials must be kept free from contact with the lamps and their holders by suitable guards or supports; celluloid or similar material must not be used for shades and candle tubes; Combustible Materials.

(*b*) Be fitted with guards if placed in positions where goods are liable to be stacked in contact with them; Guards.

(*c*) With their holders, be enclosed in air-tight fittings of thick glass, if placed in positions where they are exposed to inflammable vapour or gas, or to excessive dust or flyings, as in dust-rooms and in raising-rooms. Inflammable Gases and Dust.

86. Lamp caps of which the insulating material is hygroscopic must not be used in damp places unless the lampholder is insulated from its support. Caps.

87. Lamps of the Nernst type must comply with the requirements of paragraphs 29, 84 (*a*), (*b*), (*c*), (*d*), and 85. Nernst Lamps.

HEATERS.

88. Heaters (pars. 21 and 82 (*b*)) must be—

(*a*) so constructed and mounted that their supports and connections cannot become overheated, precau- Over-heating

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tions being taken with regard to their surroundings as in the case of non-electrical heating appliances. They must not be placed in close proximity to combustible materials, unless suitably protected ;

Switches. (*b*) independently controlled by a switch on the live side of the connector, the connectors being so arranged that the live end of the coupling is not exposed to accidental short-circuiting or injury.

Fuses and Wall-switches. 89. Radiator circuits must be protected by a fuse on each pole and by a wall-switch in each room.

RESISTANCES, CHOKING COILS, AND ALTERNATING-CURRENT TRANSFORMERS.

90. The live parts (par. 29) of the above must be—

Supporting. (*a*) carried on frames or supports and enclosed in cases. These frames, supports, and cases must be of incombustible material efficiently insulated from the conductors ;

Ventilation of Cases. (*b*) amply ventilated. Where there is danger of inflammable dust or flyings entering, apertures in the cases must be protected by fine-mesh wire gauze or by finely-perforated sheet metal ;

Size. (*c*) so proportioned that their cases cannot attain a temperature exceeding 176° F. (80° C.) ;

Combustible Materials. (*d*) so fixed that no unprotected combustible material is within 6 inches of the frames or cases containing them, or within 24 inches measured vertically above them.

MOTORS.

91. Motors (par. 29) rated at more than one-third of a horse-power must comply with the following requirements :—

(*a*) They must be protected from damp, dust, and mechanical injury

Combustible Materials. (*b*) They must be so placed that no unprotected woodwork or combustible material be within a distance of 12 inches from them measured horizontally, or within 4 feet measured vertically above them, unless they are of a totally enclosed type (par. 14).

Wood Floors. (*c*) When mounted upon wood flooring, unless of the totally enclosed or ventilated type (par. 13), they

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must have a sheet of metal inserted between them and such flooring. If elevated over wood flooring they must either rest upon a metal plate or have a metal plate suspended immediately below them.

(*d*) In positions exposed to inflammable dust or flyings, or where combustible materials are manipulated or stored, they must be either of the totally enclosed or of the ventilated type, provided that any ventilating openings in the cases of continuous-current machines are protected by fine-mesh wire gauze or by finely perforated sheet metal, and that all slip-rings, commutators, and brushes are totally enclosed. Inspection openings fitted with plate glass or fine-mesh wire gauze are allowed. Induction motors may have unprotected ventilating holes in their metal cases, but slip rings or brushes or any sliding contacts must be completely enclosed in metal cases. **Inflammab Dust.**

(*e*) They must be controlled by a switch and a fuse, or by a handgrip fuse, or by a circuit-breaker, on one conductor; and by one of these devices on the other conductor (par. 18). **Control.**

(*f*) The starting gear of a continuous-current motor must consist of a regulating switch and a series resistance, fitted with a no-volt release. **Starting Gear.**

(*g*) The shunt circuit of any motor must be so connected that the field is excited before the armature circuit is completed. **Shunt Circuit.**

(*h*) Every alternating-current motor must be provided with a suitable starting device and with a no-volt release. Large motors should have linked circuit-breakers on the conductors. **Alternating-current Motors.**

DYNAMOS.

92. Dynamos (par. 29) must comply with the following requirements:—

(*a*) They must not be placed in positions exposed to inflammable dust or flyings, nor where combustible materials are manipulated or stored. **Inflammable Dust.**

(*b*) They must be protected from damp, dust, and mechanical injury.

(*c*) They must be so placed that no unprotected wood-work, or other combustible material, be within a **Combustible Materials.**

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distance of 12 inches from them measured horizontally, or within 4 feet measured vertically above them.

Wood Floors. (*d*) When mounted upon or above wood flooring, they must have a sheet of metal inserted between them and such flooring.

Control. (*e*) They must be controlled by a switch and a fuse, or by a circuit-breaker, on one conductor; and by one of these devices on the other conductor (par. 18).

ACCUMULATORS AND OTHER BATTERIES.

Ventilation. 93. The room in which accumulators or primary batteries are placed must be well ventilated (par. 29).

Insulation. 94. The case of each cell must stand on insulators. Glass cells should have an intermediate support to distribute the strain.

Connectors. 95. Bare conductors (par. 52 (*c*)) should be used for end and regulating cell connections; and all regulating cells must be protected by a fusible connector at each cell.

Control. 96. The method of control must be as described in paragraph 91 (*e*).

TESTING.

Insulation Resistance to Earth. 97. The insulation resistance to earth of the whole or any part of the wiring must, when tested previously to the erection of fittings and electroliers, be measured with a pressure not less than twice the intended working pressure, and must not be less in megohms than 30 divided by the number of points (par. 31) under test. For this purpose the points are to be counted as the number of pairs of terminal wires from which it is proposed to take the current, either directly, or by flexibles, to lamps or other appliances.

98. Current must not be switched on until the following test has been applied to finished work :—

Testing of Circuits. The whole of the lamps having been connected to the conductors and all switches and fuses being on, a pressure equal to twice the working pressure must be applied and the insulation resistance of the whole or any part of the installation must not be less in megohms than 25 divided by the number of lamps. When all lamps and appliances have been removed from the circuit, the insulation resistance between conductors must not be less than 25 megohms divided by the number of lamps.

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The insulation of any individual sub-circuit (par. 21) must not fall below 1 megohm. Any motor, heater, arc lamp, or other appliance may be connected to the supply of electrical energy provided that the insulation of the parts carrying the current measured as above, is greater than 1 megohm from the frame or case.

99. The value of systematically inspecting and testing apparatus and circuits cannot be too strongly urged. Records should be kept of all tests, so that any gradual deterioration of the system may be detected. Cleanliness of all parts of the apparatus and fittings is essential. **Inspection.**

100. Before making any repairs or alterations, the circuits which are being attended to must be entirely disconnected from the supply. **Repairs.**

TABLE.

101. *Columns 1 and 15* give the size of the conductors in common use. Cables are shown thus :—19/16, viz., 19 wires of number 16 standard wire gauge, or 19/·082″, meaning 19 wires each of which is ·082 inch in diameter.

102. *Column 2* gives the maximum current permissible in conductors laid in casing or tubing, provided the external temperature does not exceed 100° F. (37·8° C.). The maximum current for any conductor may be calculated from the formula—

$$\text{Log } C = 0{\cdot}82 \log A + 0{\cdot}415,$$
$$\text{or } C = 2{\cdot}6\, A^{0{\cdot}82}$$

(Where C = current in amperes,
and A = sectional area in 1000ths of a square inch.)

103. *Column 3* gives the approximate current density in amperes per square inch corresponding to Column 2.

104. *Column 4* gives the total length in yards of the conductor in circuit (lead and return) for one volt drop when the current in each conductor is that given in Column 2.

105. *Columns 5 and 6* give the minimum insulation resistance (par. 40) with vulcanised rubber in megohms per mile. These insulation resistances are those of cables of I.E.E. 600 and 2,500 megohm grades, respectively.

106. *Column 7* gives the minimum insulation resistance (par. 40) which is advisable in practice for fibre-covered cables lead-covered.

107. *Column 8* gives the resistance of the conductor per 1,000 yards in Board of Trade standard ohms.

108. *Columns 9 and 10* give the minimum thickness of dielectric of Class A as defined in paragraph 38.

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109. *Column 11* gives the minimum thickness of dielectric of Class B as defined in paragraph 38. Special cables, such as twin or 3-core cables, are not included in this column.

110. *Column 12* gives the minimum thickness of lead for cables of Class B. This column does not apply to vulcanised rubber cables which may be lead-covered.

111. *Column 13* gives the weight of copper conductors of the gauge given in lbs. per 1,000 yards.

112. *Column 14* gives the nominal section of the conductor in square inches.

Standards. 113. The data for the resistances and weights of copper conductors are based on the E.S.C. standard as defined by the Engineering Standards Committee as follows:—

> A wire one metre long, weighing one gramme and having a resistance of 0·1539 standard ohms at 60° F. (15·6° C.) is taken as the Engineering Standards Committee (E.S.C.) standard for hard-drawn high conductivity commercial copper.
>
> Hard-drawn copper is defined as that which will not elongate more than 1 per cent. without fracture.
>
> A wire one metre long, weighing one gramme and having a resistance of 0·1508 standard ohms at 60° F. (15·6° C.) is taken as the Engineering Standards Committee (E.S.C.) standard for annealed high conductivity commercial copper.
>
> Copper is taken as weighing 555 lbs. per cubic foot (8·89 grammes per cubic centimetre) at 60° F. (15·6° C.) which gives a specific gravity of 8·90.
>
> An average temperature coefficient of 0·00238 per degree F. (0·00428 per degree C.) is adopted.
>
> A variation of 2 per cent. from the adopted standard of resistance is allowed in all Conductors.
>
> A variation of 2 per cent. from the adopted standard of weight is allowed in all Conductors.
>
> An allowance of 1 per cent. increased resistance, as calculated from the diameter, is allowed on all tinned copper conductors between diameters 0·104 and 0·028 (Nos. 12 and 22 S.W.G.) inclusive.
>
> For the purpose of calculation of tables, a lay, involving an increase of 2 per cent. in each wire, except the centre wire, for the total length of the cable is taken as the standard.
>
> The legal standard wire gauge, as fixed by Order in Council dated August 23, 1883, is adopted as the standard for all wires.

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BOARD OF TRADE REGULATIONS (1905) FOR MEDIUM PRESSURES, EXCEEDING 250 VOLTS, BUT NOT EXCEEDING 650 VOLTS.

[*The Regulations reprinted here are only those relating to the conditions intended to be covered by the Wiring Rules.*]

MOTORS.

1. The frame of every electric motor shall be efficiently connected with earth. **Earthing.**

2. The consumer's wires forming the connections to motors, or otherwise in connection with the supply, shall be, as far as practicable, completely enclosed in strong metal casing efficiently connected with earth, or they shall be fixed in such a manner that there shall be no danger of any shock. **Metal Casing.**

3. The supply to every motor shall be controlled by means of an efficient cut-off switch, placed in such a position as to be easily handled by the person in charge of the motor, and connected so that by its means all pressure can be cut off from the motor itself, and from any regulating switch, resistance or other device in connection therewith. **Switches.**

4. Switches, efficient fuses or other automatic circuit-breakers shall be provided, so as to protect the circuits from excess of current, and all switches and cut-outs shall be so enclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof, or of any fire being caused by their normal or abnormal action. **Protection Against Excess of Current, Shock, and Fire.**

5. A notice shall be fixed in a conspicuous position at every motor and switchboard in connection with the supply forbidding unauthorised persons to touch the motors or apparatus. **Danger Notices.**

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ARC LAMPS IN SERIES.

Metal Casing.

1. The consumer's wires forming the connections to the arc lamps, or otherwise in connection with the supply, shall be, as far as practicable, completely enclosed in strong metal casing efficiently connected with earth, or they shall be fixed in such a manner that there shall be no danger of any shock.

Switches.

2. The supply to every arc lamp shall be controlled by means of an efficient cut-off switch, placed in such a position as to be easily handled by the person in charge of the arc lighting, and connected so that by its means all pressure can be cut off from the arc lamp itself, and from any regulating switch, resistance or other device in connection therewith. Provided that where the arc lamps are connected in series across the outer conductors of a three-wire system, it shall be sufficient if one such switch be provided for each series of arc lamps.

Protection Against Excess of Current, Shock, and Fire.

3. Switches, efficient fuses or other automatic cut-outs shall be provided, so as to protect the circuits from excess of current, and all switches and cut-outs shall be so enclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof, or of any fire being caused by their normal or abnormal action.

INCANDESCENT LAMPS IN SERIES.

Metal Casing.

1. The consumer's wires forming the connections to the incandescent lamps, or otherwise in connection with the supply, shall be completely enclosed in strong metal casing and this casing together with the switches and lamp holders, if metallic, shall be efficiently connected with earth.

Protection Against Excess of Current, Shock, and Fire.

2. Switches, efficient fuses or other automatic cut-outs shall be provided, so as to protect the circuits from excess of current, and all switches and cut-outs shall be so enclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof, or of any fire being caused by their normal or abnormal action.

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HOME OFFICE SPECIAL RULES (1905) FOR THE INSTALLATION AND USE OF ELECTRICITY IN MINES.

[*The following Rules shall be observed, as far as is reasonably practicable, in the Mine.*]

DEFINITIONS.

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and earth as read by a hot wire or electrostatic volt-meter, and

(*a*) Where the conditions of the supply are such that the pressure at the terminals where the electricity is used cannot exceed 250 volts, the supply shall be deemed a low-pressure supply.

(*b*) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 250 volts, but cannot exceed 650 volts, the supply shall be deemed a medium-pressure supply.

(*c*) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 650 volts, but cannot exceed 3,000 volts, the supply shall be deemed a high-pressure supply.

(*d*) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 3,000 volts, the supply shall be deemed an extra high-pressure supply.

SECTION I.

GENERAL.

1. (*a*) All electrical apparatus and conductors shall be sufficient in size and power for the work they may be called upon

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to do, and, so far as is reasonably practicable, efficiently covered or safeguarded, and so installed, worked, and maintained as to reduce the danger through accidental shock or fire to the minimum, and shall be of such construction, and so worked that the rise in temperature caused by ordinary working will not injure the insulating materials.

(*b*) In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the covering shall be constructed so that, as far as is reasonably practicable, there is no danger of firing gas by sparking or flashing which may occur during the normal or abnormal working of the apparatus.

(*c*) All metallic coverings, armouring of cables, other than trailing cables, and the frames and bedplates of generators, transformers, and motors other than portable motors, shall, as far as is reasonably practicable, be efficiently earthed where the pressure at the terminals where the electricity is used exceeds the limits of low pressure.

2. Where a medium-pressure supply is used for power purposes, or for arc lamps in series, the wires or conductors forming the connections to the motors, transformers, arc lamps, or otherwise in connection with the supply, shall be, as far as is reasonably practicable, completely enclosed in strong armouring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner, that danger from fire or shock may be reduced to the minimum. This rule shall not apply to trailing cables.

3. Where a medium-pressure supply is used for incandescent lamps in series, the wires or conductors forming connections to the incandescent lamps, or otherwise in connection with the supply, shall be, as far as is reasonably practicable, completely enclosed in strong armouring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner that danger from fire or shock shall be reduced to the minimum.

4. Motors of coal-cutting and such other portable machines shall not be used at a pressure higher than medium pressure. No transformer used for supplying current at a pressure higher than medium pressure and no motor using such current shall be of less normal rating than 20 b.h.p. for use underground.

No higher pressure than a medium pressure shall be used in any place or part of the mine to which General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies.

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5. No higher pressure than a medium-pressure supply shall be used other than for transmission or for motors, and the wires or conductors other than overhead lines above ground forming the connections to the motors or transformers or otherwise in connection with the supply shall be completely enclosed in a strong armouring or metal casing efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner that danger from fire or shock shall be reduced to the minimum.

The machines, apparatus, and lines shall be so marked as to clearly indicate that they are high pressure, either by the use of the word "Danger" at frequent intervals, or by red paint properly renewed when necessary.

6. The insulation of every complete circuit other than telephone or signal wires used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connection with such circuit, shall be so maintained that the leakage current shall, so far as is reasonably practicable, not exceed $\frac{1}{1000}$ of the maximum supply current, and suitable means shall be provided for the immediate localisation of leakage.

7. In every completely insulated circuit, earth or fault detectors shall be kept connected up in every generating and transforming station, to show immediately any defect in the insulation of the system. The readings of these instruments shall be recorded daily in a book kept at the generating or transforming station or switch-house.

8. Main and distribution switch and fuse boards must be made of incombustible insulating material, such as marble or slate free from metallic veins, and be fixed in as dry a situation as practicable.

9. Every sub-circuit must be protected by a fuse on each pole. Every circuit carrying more than 5 amperes up to 125 volts or 3 amperes at any pressure above 125 volts, must be protected in one of the following alternative methods :—

(*a*) By an automatic maximum cut-out on each pole.

(*b*) By a detachable fuse on each pole, constructed in such a manner that it can be removed from a live circuit with the minimum risk of shock.

(*c*) By a switch and fuse on each pole.

10. Fire buckets, filled with clean, dry sand, shall be kept in electrical machine rooms, ready for immediate use in extinguishing fires.

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No repair or cleaning of the live parts of any electrical apparatus except mere wiping or oiling shall be done when the current is on.

Gloves, mats, or shoes of indiarubber of other non-conducting material shall be supplied and used where the live parts of switches or machines working at a pressure exceeding the limits of low pressure have to be handled for the purpose of adjustment.

11. A competent person shall be on duty at the mine when the electrical apparatus or machinery is in use; and at such time as the amount of electricity delivered down the mine exceeds 200 b.h.p., a competent person shall be on duty at the mine above ground, and another below ground. Every person appointed to work any electric apparatus shall have been instructed in his duty and be competent for the work that he is set to do.

12. No person shall wilfully damage, interfere with, or without proper authority remove or render useless any electric line or any machine, apparatus, or part thereof, used in connection with the supply or use of electricity.

13. Instructions shall be posted up in every generating, transforming, and motor house containing directions as to the restoration of persons suffering from electric shock.

14. Direct telephonic or other equivalent means of communication shall be provided between the surface and the pit bottom or main distributing centre in the pit.

15. Within three months after the introduction into any mine of electric motive power, notice in writing must be sent to H.M. Inspector of Mines for the district. Notice must also be sent of any existing electric motive-power installation at any mine within three months after the coming into force of these rules.

16. A plan shall be kept at the mine showing the position of all permanent electrical machinery and cables in the mine, and shall be corrected as often as may be necessary to keep it up to a date not more than three months previously.

SECTION II.

GENERATING STATIONS AND MACHINE ROOMS.

17. Where the generating station under the control of the owner or manager of the mine is not within 400 yards of the working pit mouth, an efficiently enclosed locked switch box or boxes, or a switch-house, shall, where reasonably practicable,

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be provided near the pit mouth, for cutting off the supply of electricity to the mine.

18. There shall be a passage way in front of the switchboard of not less than 3 ft. in width, and if there are any connections at the back of the switchboard, any passage way behind the switchboard shall not be less than 3 ft. clear. This space shall not be utilised as a storeroom or a lumber room, or obstructed in any manner by resistance frames, meters, or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passage way must be widened accordingly.

No cable shall cross the passage way at the back of the board except below the floor, or at a height of not less than 7 ft. above the floor.

The space at the back of the switchboards shall be properly floored, accessible from each end, and, except in the case of low-pressure switchboards, must be kept locked up, but the lock must allow of the door being opened from the inside without the use of a key. The floor at the back shall be incombustible, firm and even.

19. Every generator shall be provided with a switch on each pole between the generator and the bus-bars.

When continuous-current generators are paralleled, reversed current cut-outs shall also be provided.

Suitable instruments shall be provided for measuring the current and pressure of each generator.

Every feeder circuit shall at its origin be provided with an ammeter.

20. If the transmission lines from the generating station to the pit are overhead there shall be lightning arresters in connection with the feeder circuits.

21. Automatic cut-outs must be arranged so that when the contact lever opens outwards no danger exists of striking the head of the attendant. If unenclosed fuses are used they must be placed within 2 ft. of the floor, or be otherwise suitably protected.

Where the supply is at a pressure exceeding the limits of medium pressure, there shall be no live metal work on the front of the main switchboard within 8 ft. of the floor or platform, and the space provided under Rule No. 2 of this section shall be not less than 4 ft. in the clear. Insulating floors or mats shall be provided for medium-pressure boards where live metal work is on the front or back.

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22. All terminals and live metal on machines over medium pressure above ground, and over low pressure under ground, where practicable shall be protected with insulating covers or with metal covers connected to earth.

23. No person other than an authorised person shall enter a machine or motor room, or interfere with the working of any machine, motor, or apparatus connected therewith.

SECTION III.

CABLES.

24. All conductors (except as hereinafter provided) shall in every case be maintained completely insulated from earth, but it is permissible to use the concentric system with earthed outer conductor, if proper arrangements are made to reduce the danger from fire or shock to the minimum, but the neutral point of polyphase systems and the middle wire of three-wire continuous-current systems may be earthed at one point.

25. Unless fixed as far as is reasonably practicable out of reach of injury, all conductors, other than armoured cables, must further be protected by a suitable covering. Where lead-covered cable is used the lead shall be earthed, and electrically continuous throughout.

The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances, must as far as is reasonably practicable be properly protected and finished off, so that moisture cannot creep along the insulating material within the waterproof sheath, nor can the insulating material, if of an oily nature, leak out of the cable.

26. All joints must be mechanically and electrically efficient, and, where reasonably practicable, must be suitably soldered. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, suitable joint boxes must be used, and the conductors connected by means of metal screw clamps, connectors, or their equivalent, constructed in a safe manner. Provided that in any place or part of a mine where a shot may be fired joints may be soldered by or in the presence of a person authorised in that behalf by the manager, but the same precautions in regard to examination and removal of workmen as are prescribed by paragraphs (*f*) and (*i*) of General Rule 12 shall be observed in all cases, and where the place is dry and dusty, also the precautions as to watering

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prescribed by paragraph (*h*). Wires, other than signalling wires, or cables must not be joined by merely twisting them together.

27. Overhead bare wires on the surface must be efficiently supported upon insulators, and clear of any traffic, and provided with efficient lightning arresters.

28. All cables used in shafts must be highly insulated and substantially fixed. Shaft cables, not capable of sustaining their own weight, shall be properly supported at intervals varying according to the weight of the cable. Where the cables are not completely boxed in and protected from falling material, space shall be left between them and the side of the shaft that they may yield, and so lessen a blow given by falling material.

29. Where the cables in main haulage roads cannot be kept at least 1 foot from any part of the tub or tram, they shall be specially protected. When separate cables are used they shall, if reasonably practicable, be fixed on opposite sides of the road.

The fixing with metallic fastenings of cables and wires not provided with metallic covering to walls or timbers is prohibited.

Cables underground when suspended shall be suspended by leather or other flexible material in such a manner as to allow of their readily breaking away when struck, before the cables themselves can be seriously damaged.

Where main or other roads are being repaired, or blasting is being carried out, suitable temporary protection must be used so that the cables are reasonably protected from damage.

30. Trailing cables for portable machines shall be specially flexible, heavily insulated, and protected with either galvanised steel wire armouring, extra stout braiding, hose pipe, or other effective covering. Trailing cables shall be examined at least once in each shift by the person in charge of the machine, and any defects in them promptly repaired.

At points where the flexible conductors are joined to the main cables, a fixed terminal box must be provided, and a switch shall be fixed close to or in the terminal box capable of entirely cutting off the supply from the terminal box and motor.

SECTION IV.

SWITCHES, FUSES, AND CUT OUTS.

31. Fuses and automatic cut-outs shall be so constructed as effectually to interrupt the current when a short circuit occurs,

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or when the current through them exceeds the working current by 200 per cent. Fuses shall be stamped or marked, or shall have a label attached, indicating the current with which they are intended to be used, or where fuse wire is used each coil in use shall be so stamped or labelled. Fuses shall only be adjusted or replaced by an authorised person.

32. All live parts of switches, fuses, and cut-outs not in machine rooms, or in compartments specially arranged for the purpose, must be covered. These covers must be of incombustible material, and must be either non-conducting or of rigid metal, and, as far as practicable, clear of all internal mechanism.

33. All points at which a circuit other than those for signals has to be made or broken shall be fitted with proper switches. The use of hooks or other makeshifts is prohibited, and in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the use of open-type switches, fuses, and cut-outs is prohibited; they must either be enclosed in gas-tight boxes, or break under oil.

SECTION V.

MOTORS.

34. All motors, together with their starting resistances, shall be protected by switches capable of entirely cutting off the pressure, and fixed in a convenient position near the motor, and every motor of 10 b.h.p. or over in a machine room underground shall be provided with a suitable ammeter to indicate the load put upon the machine.

35. Where unarmoured cables or wires pass through metal frames or into boxes or motor casings, the holes must be substantially bushed with insulating bushes, and, where necessary, with gas-tight bushings which cannot readily become displaced.

36. Terminal boxes of portable motors must be securely attached to the machine, or be designed to form a part thereof.

37. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, all motors, unless placed in such rooms as are separately ventilated with intake air, shall have all their current-carrying parts, also their starters, terminals, and connections completely enclosed in flame-tight enclosures, made of uninflammable material, and of sufficient strength as not to be liable to be damaged should an explosion of firedamp occur in the interior, and such enclosures shall not be opened except by an authorised person, and then

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only when the current is switched off. The pressure shall not be switched on while the enclosures are open.

38. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, a safety lamp or other suitable apparatus for the detection of firedamp shall be provided for use with each machine when working, and should any indication of firedamp appear on the flame of the safety lamp or other apparatus used for the detection of firedamp, the person in charge shall immediately stop the machine, cut off the current at the gate end or nearest switch, and report the matter to an official of the mine.

39. (*a*) A coal-cutter motor shall not be kept continuously at work for a period of time exceeding a maximum period which shall be specified in writing by the manager, so that the roof may be carefully examined.

(*b*) The casing or inspection doors of all portable motors used underground and the casings of their switches and other appliances shall at least once a week be opened by a competent person appointed by the manager, and the parts so disclosed shall be cleaned and examined before the coverings are replaced. In special cases requiring a motor to run continuously longer than one week, the motor shall be examined at the end of the run. A report of such examination shall be entered in a report book.

40. The person in charge of a coal-cutter or drilling machine shall not leave the machine while it is working, and shall, before leaving the working place, see that the current is cut off from the trailing cables. He must not allow the cables to be dragged along by the machine. No repairs shall be made to any portable machine until the pressure has been cut off from the trailing cables.

41. If any electric sparking or arc be produced outside a coal-cutting or other portable motor or by the cables or rails, the machine shall be stopped, and not be worked again until the defect is repaired, and the occurrence shall be reported to an official of the mine.

SECTION VI.

ELECTRIC LOCOMOTIVES.

42. Electric haulage by locomotives by the trolley wire system is not permissible in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887,

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applies. On this system no pressure exceeding the limits of medium pressure may be employed.

43. In underground roads the trolley wires must be placed so that they are at least 7 ft. above the level of the road or track, or elsewhere, if sufficiently guarded, or the pressure must be cut off from the wires during such hours as the roads are used for travelling on foot in places where trolley wires are fixed. The hours during which travelling on foot is permitted shall be clearly indicated by notices and signals placed in a conspicuous position at the ends of the roads. At other times no one other than a duly authorised person shall be permitted to travel on foot along the road.

On this system either insulated returns or uninsulated metallic returns of low resistance may be employed.

44. In order to prevent any other part of the system being earthed (except when the concentric system with earthed outer conductor is used), the current supplied for use on the trolley wires with an uninsulated return shall be generated by a separate machine, and shall not be taken from or be in connection with electric lines otherwise completely insulated from earth.

45. If storage battery locomotives are used in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the rules applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

SECTION VII.

ELECTRIC LIGHTING.

46. All arc lamps shall be so guarded as to prevent pieces of ignited carbon falling from them, and shall not be used in situations where there is likely to be danger from the presence of coaldust. They should be so screened as to prevent risk of contact with persons.

47. Small wires for lighting circuits must be either conveyed in pipes or casings, or suspended from porcelain insulators, or tied to them with some non-conducting material which will not cut the covering, and so that they do not touch any timbering or metal work. On no account must staples be used. If metallic pipes are used they must be electrically continuous and earthed. If separate uncased wires are used they must be kept at least 2 in. apart, and not brought together except at lamps or switches or fittings.

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48. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, electrical lamps, if used, must be of the vacuum or enclosed type ; they shall be protected by gas-tight fittings of strong glass, and have no flexible cord connections, and shall only be changed by a duly authorised competent person. While the lamps are being changed the current shall be switched off.

49. In all machine rooms and other places underground, where a failure of electric light is likely to cause danger, some safety lamps, or other proper lights, shall be kept for use in the event of such failure.

SECTION VIII.

SHOT-FIRING.

50. Electricity from lighting or power cables shall not be used for firing shots, except in sinking shafts or stone drifts, and then only when a special firing plug, button, or switch is provided, which plug, button, or switch shall be placed in a fixed locked box, and shall only be accessible to the authorised shot-firer.

The firing cables or wires shall not be connected to this box until immediately before it is required for the firing of shots, and shall be disconnected immediately after the shots are fired.

When shot-firing cables or wires are used in the vicinity of power or lighting cables, sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming in contact with the lighting or power cables.

The foregoing rules shall not apply to telephone, telegraph, and signal wires, to which the rules of this section only shall apply.

SECTION IX.

SIGNALLING.

51. All proper precautions must be taken to prevent electric signal and telephone wires from coming into contact with other electric conductors, whether insulated or not.

52. Contact makers or push buttons of electric signalling circuits shall be so constructed and placed as to prevent the circuit being accidentally closed.

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53. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, bare wires shall not be used for signalling circuits except in haulage roads, and the pressure shall not exceed 15 volts in any one circuit.

SECTION X.

ELECTRIC RELIGHTING OF SAFETY LAMPS.

54. In mines to any place or part of which General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, when safety lamps are relighted underground by electricity, the manager shall select a suitable station or stations, which are not in the return airway, and in which there is not likely to be any accumulation of inflammable gas; and no electric relighting apparatus shall be used in any other place. All electrical relighting apparatus shall be securely locked, so as not to be available for use except by persons authorised by the manager to relight safety lamps, and such persons shall examine all safety lamps brought for relighting before they are re-issued.

SECTION XI.

EXEMPTIONS AND MISCELLANEOUS.

55. Notwithstanding anything contained in these rules, any electrical plant or apparatus installed or in use before the coming into force of these rules may be continued in use unless an inspector shall otherwise direct, or subject to any conditions affecting safety that he may prescribe.

In case any difference of opinion shall arise between an inspector and an owner under this Rule, the same shall be settled as provided in section 42 of the Coal Mines Regulation Act, 1887.

56. Any of the foregoing requirements shall not apply in any case in which exemption is obtained from the Secretary of State, on the ground either of emergency or special circumstances, on such conditions as the Secretary of State may prescribe.

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SHOWIN[illegible]D COPPER CONDUCTORS.

Gauge. Number of wires and gauge in S.W.G. or inches. 1.	*Amperes.* Maximum amperes permissible. 2.	*Weight.* Weight of copper conductors per 1,000 yards. 13.	*Section.* Nominal sectional area of conductors. 14.	*Gauge.* Number of wires and gauge in S.W.G. or inches. 15.
	Amperes.	Lbs.	Sq. Inches.	
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// JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 39. 1907. No. 185.

Proceedings of the Four Hundred and Fifty-seventh Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 25, 1907—Dr. R. T. GLAZEBROOK, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on April 18, 1907, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS

From the class of Associate Members to that of Members :—

David Alexander. | Frank M. Biliotti.

From the class of Associates to that of Members :—

Francis E. Benest.

From the Class of Associates to that of Associate Members :—

Samuel Blackley. | James Caldwell.

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From the class of Students to that of Associate Members :—

Ernest Ambrose. | Capel C. Berger.
Walter J. Line.

Messrs. B. B. Heaviside and L. C. B. Trimnell were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Member.

Roger Thomas Smith.

As Associate Members.

Arthur William Ashton.	Robert Edmund Moynihan.
Francis Henry Davies.	John James Rudall Overton.
James Charles Elvy.	Frederick Walford Parkes.
George Maurice Gibbins.	Adolphus Reginald Z. Porter.
William George Hamilton.	Reuben Robinson.
Henry Ashley Madge.	Cyril Hunter Robert Thorn.

Arthur Willis.

As Students.

Frank James Brookes.	Philip Franklin Lloyd.
Alfred Melbourne Coates.	Norman Miller.
John Ashworth Crabtree.	Charles Harry Platt.
John Robert Davies.	Frank Chester Sharp.
Charles Henry Genève.	John Francis Stein.
Patrick Mackintosh Hogg.	Stuart Boyle Sutherland.
Arthur Johnson.	Sidney Wallace Trentham.
Charles E. H. Lethbridge-Walter.	Albert Edward Uffelmann.
	Wallace Devenport Vick.

Frederick Herbert Williams.

The PRESIDENT read the following list of Council nominations for the offices and Council for the ensuing Session :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE, 1907–08.

As President.

Nomination LORD KELVIN, P.C., O.M., G.C.V.O., F.R.S.

As Vice-Presidents (4).

Remaining in Office { F. GILL.
C. P. SPARKS.

New Nominations { COL. H. C. L. HOLDEN, R.A., F.R.S.
PROFESSOR G. KAPP.

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As Ordinary Members of Council.

Remaining in Office	W. DUDDELL, F.R.S. S. EVERSHED. H. E. HARRISON, B.Sc. WALTER JUDD. J. E. KINGSBURY. M. O'GORMAN. G. H. PARTRIDGE. A. A. C. SWINTON. C. H. WORDINGHAM.
New Nominations	DR. E. HOPKINSON. J. W. JACOMB-HOOD. W. M. MORDEY. W. H. PATCHELL. S. L. PEARCE. W. RUTHERFORD.

As Associate Members of Council.

Remaining in Office	A. CAMPBELL. J. HUNTER GRAY.
New Nomination	H. HUMAN.

As Honorary Treasurer.

For Re-election	ROBERT HAMMOND.

As Honorary Auditors.

For Re-election	H. ALABASTER. SIDNEY SHARP.

The following paper was read and discussed :—

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DEPRECIATION.

By ROBERT HAMMOND, Member of Council.

(Paper read April 25, 1907.)

In arriving at the net profits earned during any given period by an industrial undertaking, it is obvious that a determination should be made of the extent to which the assets of the undertaking have depreciated in value during that period. Where machinery and apparatus are employed it is necessary to estimate their probable "life," which, in the case of undertakings working on well-established lines, may be easily arrived at.

Having fixed a definite figure for the life, the sum which is equivalent to the annual depreciation of the machinery and apparatus may be written off annually and debited to the gross profits, this book entry involving no withdrawal of money from the undertaking; or out of the gross profits, annual investments may be made of such sums as will, at compound interest, reach the amount of the original cost of the machinery and apparatus by the time that they are worn out.

To take an illustration. Let us presume that machinery and apparatus have been acquired at a cost of £100,000, and that twenty-five years has been fixed as the probable life.

If it be decided to invest the depreciation fund in the undertaking, a sum of £4,000 should be debited annually for twenty-five years to "gross profits" and credited to machinery and apparatus, thereby reducing its book value from £100,000 at the start to nil at the end of the twenty-five years.

Or, if it be decided to keep the depreciation fund intact and to invest it in securities yielding, say, 3 per cent., it will be necessary out of the gross profits to set aside annually the sum of £2,742 16s. Such annual investments bearing compound interest at 3 per cent. per annum will reach £100,000 at the end of the twenty-five years.

Turning to electricity supply undertakings one finds that their development has been so rapid, and the working conditions have so greatly altered in so short a time, that no standard method has yet been agreed upon for dealing with the question of depreciation, and no definite course has been pursued either by companies or by local authorities.

In the case of undertakings owned by local authorities the issue has indeed been somewhat obscured by the controversial questions

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which seem inseparable from all municipal undertakings, and by the difference between the financial basis of these undertakings and that of most other industrial concerns.

The object of the present paper is to invite the members of the Institution to consider the question of depreciation in all its bearings as applicable to electricity supply undertakings, in the hope that some definite conclusion may be arrived at as to the proper provision which should be made in the case of undertakings owned, whether by companies or by local authorities.

The word "depreciation" is used in a wide sense, and it is desired to include in the inquiry not only the consideration of the provision which should be made to cover the depreciation in value of the assets of an undertaking, but also as to what other charges beyond the ordinary working costs should be debited to the revenue account before arriving at the net profits of the undertaking.

Following these lines we have first to consider the question of depreciation proper, then the advisability of creating a reserve fund to provide for unforeseen expenses which may be incurred owing to accident or other emergency, and, lastly, the provision of a further fund to cover antiquation of machinery, apparatus, and mains, thereby preparing for the possible necessity of scrapping machinery, etc., which may be in good working order, but which may have become obsolete owing to improvements introduced in methods of generation and distribution.

In the case of undertakings owned by companies, the consideration of these questions resolves itself merely into what should be the amount of the provision to be set aside annually from the gross profits in connection with the above items.

In the case of undertakings owned by local authorities, on the other hand, not only is it necessary to consider the amount to be provided under the three heads of depreciation, extraordinary emergencies, and antiquation, but a more controversial point arises, viz., the effect of the peculiar financial basis on which such undertakings rest, upon the necessity for these provisions.

Companies.

Obviously the two classes of undertakings must be considered separately, though in many respects there are points common to both.

Whether the undertakings are owned by companies or by local authorities the conditions governing their working are such that in order to give a continuous supply of electricity it is essential that machinery, apparatus, and mains, should be kept in a high state of efficiency.

The cost of so maintaining the plant is, of course, regarded as part of the working costs, and is assumed to be so dealt with. Plant, well maintained as it may be, must, however, gradually depreciate, and a time will come when the frequency and extent of repairs and renewals

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necessitate so heavy an item of annual expenditure that it is preferable to replace it with entirely new plant.

In order to arrive at the amount with which the gross profits should be debited annually in order to cover this depreciation, it is necessary to settle the number of years which will elapse before the various classes of plant and apparatus in use will arrive at the scrapping stage and will require entire renewal.

At the outset we are confronted with the difficulty that the life of machinery so largely depends upon the way in which it is maintained, that a definite period, at which any particular class of machinery or apparatus would in the ordinary course be entirely worn out, can hardly be taken as of universal application.

On the basis, however, that all plant would be carefully maintained and faulty parts renewed out of revenue, it is suggested that the periods named below represent a fair approximation of the life of the various classes of machinery and apparatus, etc., named :—

ESTIMATED YEARS OF LIFE.

	Years
Land and Buildings	60
Machinery and Plant :—	
Boilers	20
Pumps and Pipework	25
Conveyors	10
Engines	25
Turbines	20
Dynamos and Alternators...	25
Motors	20
Tools and Sundries	10
Accumulators	15
Transformers, Static	25
Converters, Rotary	20
Switching Apparatus and Instruments ...	20
Meters	10
Mains :—	
Armoured	25
"Solid" System	30
"Ducts" System	30

The "lives" set forth will doubtless provoke some criticism, but it is repeated that the "life" largely depends upon the degree of thoroughness with which the plant is maintained.

With accumulators, for instance, it seems sanguine at first sight to give a life of fifteen years. Further consideration shows, however, that for all practical puposes, with careful upkeep, the life given is merely that of the boxes containing the plates, connections, etc. There is no reason why a battery of accumulators should not last considerably longer than fifteen years if the plates are regularly renewed out of revenue.

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If the above periods be accepted, it becomes a simple calculation as to the amount which must annually be written off or set aside to a sinking fund.

Reference has already been made to the alternative methods of dealing with the depreciation fund. Of those methods doubtless the sounder is that which provides for the annual investment, outside the undertaking, of such sums as will, accumulated at compound interest, represent from time to time the actual ageing of the machinery, apparatus, mains, etc.

It is true that if this method were adopted, each extension of the undertaking would necessitate the raising of fresh capital which would have to be subscribed either by the existing shareholders or by the general public. Although this might cause inconvenience, yet, nevertheless, it is urged that by this method a far more definite control would be established over the growth of the undertaking, and the shareholders would have the option of either investing or refraining from investing further capital in it instead of being compelled to do so through the investment of the depreciation fund monies in it.

It is also urged that should the course advocated be pursued, the company with such an asset at its back would be in a far more favourable position as regards the issue of fresh share capital than it would be if it had invested its depreciation fund in extensions and was compelled to go to the public for more capital, at a time when a large proportion of its machinery and plant had become worn out.

In support of this contention it is pointed out that in many undertakings not only is the existing plant written down in value in the balance sheet, but since the balance so obtained does not exist in cash, it has been considered necessary to form a separate fund, called a renewals fund, which is retained as cash for the purpose of renewing such items as have an exceedingly short life, such as the track in a tramway undertaking.

It seems to be unreasonable that profits should be debited not only with depreciation but also with contributions to a renewals fund. If the depreciation fund existed in readily convertible securities instead of being invested in the undertaking for extensions and the like, it would be available, in the case of a tramway company, to renew the track as soon as the rails were worn out, and the monies otherwise placed to the renewal fund would have been distributed as profits.

One, of course, gets back to the fact that for the purpose of extensions, fresh issues of capital would be required from time to time, and most directors would doubtless think it preferable to use the money which they had actually in hand before they made an appeal to their shareholders or to the outside public for further share capital. This indeed is the method that has almost universally been adopted by the electricity supply companies operating in the metropolis.

So far, the formation of a depreciation fund in the narrow sense of the word has alone been dealt with. The formation of such a fund, apart from the method of accountancy adopted, appears to be essential

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whether the company is working at a profit or a loss. In the event of its working at a loss for, let us suppose, the first few years, it seems only sound that before any monies are distributed as dividends, not only should the trading losses be made good, but the contributions to the depreciation fund which otherwise would have been set aside should also be made.

As regards the second item, to which reference has already been made as coming within the purview of the paper, namely, the provision of a general reserve fund, it seems to the author that, however wise the formation of a general reserve fund might be for the purpose of equalisation of dividends, it nevertheless does not rank as a strict necessity as does a depreciation fund. Further, he does not agree with those who hold that such a fund is necessary, not only for the equalisation of dividends, but for the purpose of providing against extraordinary expenditure due to unforeseen emergencies.

Such emergencies are caused by accident in one form or another, and such risks should be fully insured against and the premiums regarded as part of the ordinary working costs.

Lastly, there is to be considered whether a fund to cover antiquation should be deemed obligatory.

It has been urged on the one hand that no provision whatever need be made under this heading.

Those who hold this view contend that any great revolution in engineering methods which would cause their present plant to become obsolete would necessarily carry with it its own advantages either in the direction of a great improvement in efficiency or in an extension of the uses to which electricity might be put.

They contend that these advantages if really extensive would in themselves more than pay for their adoption, and that unless a company could see its way to larger dividends by adopting an improvement, it would, of course, continue on the old lines.

On the other hand, many hold the view that an antiquation fund is of vital importance, and they point out that a radical improvement might arise which entirely superseded the existing methods of generation and distribution, and while such an improvement would entirely take the field in opposition to the present methods, nevertheless the improvement might not carry with itself a sufficient margin of profit to cope with the dead weight of interest on capital expended upon superseded plant.

A company which was without an antiquation fund would then be faced by the possible competition of a new concern not so overburdened with capital charges, which could completely relieve them of their business.

The author does not share the latter view to the full extent, but, on the other hand, he thinks that no electricity supply undertaking can be regarded as in a thoroughly sound position unless some provision has been made in the direction of an antiquation fund. At the same time this provision is, in his opinion, not one which would rank on the same

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footing as a depreciation fund *per se*, but is one which might wisely be contributed to out of profits as a sort of nest-egg for the future.

The distinction which he desires to draw between the contributions to a depreciation fund and contributions to an antiquation fund is practically that the former should be built up whether the undertaking is working at a loss or not, while contributions to the latter fund need only be regarded as advisable when a concern is in a flourishing condition.

LOCAL AUTHORITIES.

In considering the case of local authorities owning electricity supply undertakings, it is seen that their method of raising the capital precludes them from adopting the plan in vogue among the companies of writing down the value of their machinery, apparatus, etc., and keeping the money in the business.

Members of the Institution, are, of course, aware that the capital expenditure required in connection with undertakings owned by local authorities is raised in the United Kingdom by means of loans upon the security of the general district rate, such loans having to be repaid at certain definite periods. These repayments are secured by the creation of sinking funds, the annual payments to the sinking funds being provided out of the revenue of the undertaking, any deficit which may arise being met by a charge upon the rates.

In the case of loans authorised by the Local Government Board the practice hitherto has been to allow a period of twenty-five years for the repayment of loans required for electricity supply undertakings.

The period of twenty-five years is supposed to represent the average life of the various sets of machinery, apparatus, and of the mains, buildings, etc., upon which the capital expenditure is to be incurred. That is to say, that while the life of such items as land, buildings, etc., is well over twenty-five years, on the other hand expenditure is incurred upon pieces of apparatus whose life is considerably less than twenty-five years.

While perhaps it does not bear strictly upon the subject-matter of this paper, reference may be made, in connection with the life of various portions of the plant, to the system by which one may arrive at an equated period for a loan which covers the purchase of various apparatus and machinery, with varying "lives."

The method of arriving at the equated period, in common vogue, is to take the average of the lives, taking into consideration, of course, the different monetary values.

As a matter of fact this method can only give a more or less correct approximation of the true equated period. When the rate of interest payable on the sinking fund is a comparatively low one, and the various periods are not greatly dissimilar, the result obtained by averaging the lives does not differ widely from the result obtained by calculating the true equated period. On the other hand, under other conditions which are quite likely to obtain in practice, the divergence may be considerable.

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Perhaps it should be explained what the author means by the use of the words "The true equated period."

In dealing with a number of loans for various periods of years, two courses are open to the borrower. He may either deal separately with each separate loan and pay each off as it becomes due, or he may arrange with the lenders to *equate* the whole of the loans, and thus enable him to erect one sinking fund, and to pay off the whole amount of his indebtedness at one time.

From both the point of view of the borrower and the lender, it is, of course, an axiom that whichever of these two courses be adopted, neither party shall be the loser from a financial point of view. In other words, the arrangement must be such that the present value to the lender of the combined loan, repaid at the equated period, must be exactly the same as the present value to the lender of all the separate loans.

In arriving, therefore, at the true equated period of a number of loans, it is not sufficient to take the mean value of the lives of the assets and thus to ignore the compound interest question. The exact method is to arrive by calculation at a period of years such that, if the total amount of the various loans were repayable at the end of that period, the present value of that loan would be equal to the present value of all the separate loans repaid at their various individual periods.

As stated above, the difference between the results arrived at by these two methods is not great when the rate of interest at which the sinking fund is invested is about 3 per cent., and when the different periods are not greatly dissimilar. When, however, the periods to be equated differ widely, or when the rate of interest is a higher one, considerable difference appears, as may be shown by the following example:—

Let the loans set out below be obtained and be repayable at the expiration of the periods named:—

£20,000	repayable	in 60	years
£30,000	"	" 25	"
£10,000	"	" 15	"
£10,000	"	" 10	"

The average of the above periods is 31·43 years, arrived at as follows:—

$$\begin{array}{rr} 20,000 \times 60 = & 1,200,000 \\ 30,000 \times 25 = & 750,000 \\ 10,000 \times 15 = & 150,000 \\ 10,000 \times 10 = & 100,000 \\ \hline 70,000 \qquad & 2,200,000 \end{array}$$

$$\frac{2,200,000}{70,000} = 31{\cdot}43.$$

The present value of	£20,000 due	60 years hence	at 3 % is	£3,394·6
" "	30,000 "	25 "	"	14,328·3
" "	10,000 "	15 "	"	6,418·6
" "	10,000 "	10 "	"	7,440·9
Total of loans	£70,000		Total of present values	£31,582·4

To obtain the required equated period it is only necessary to calculate the number of years (n) at which £70,000 would be due in order to have a present value of £31,582·4 :—

$$\frac{70{,}000}{1{\cdot}03^n} = 31{,}582{\cdot}4$$

$$n = \frac{\log 70{,}000 - \log 31{,}582{\cdot}4}{\log 1{\cdot}03}$$

$$n = 26{\cdot}92.$$

In the past it has often been contended that in the case of local authorities no further provision for depreciation beyond the sinking fund payments is necessary in arriving at the true annual profits, owing to the fact that the annual contributions to sinking fund are such that by the time the plant has been worn out, the indebtedness in respect of the capital expenditure on same will have been extinguished.

The opponents of municipal trading have not only strongly contested this view, but the discussion has been further complicated by attacks on the period of twenty-five years, arived at by the equation of the lives of the various portions of the plant.

Apart, however, from the soundness of the basis taken in arriving at the equated period for repayment of loans, the opponents of municipal trading have contended that not only should annual contributions to the sinking funds be made of such amounts as will be sufficient to extinguish the indebtedness at the end of the loan periods, but that further contributions should be made either from revenue or from the rate fund of such amounts as would provide a fund sufficient entirely to renew the machinery, apparatus, mains, etc., without incurring fresh indebtedness when the original "outfit" is worn out. That is to say, it is sought to burden the undertakings of local authorities not only with the instalments by which their indebtedness is extinguished, but with further contributions in the form of "provisions for depreciation" equal in amount to what would be set aside for that purpose in the case of undertakings belonging to companies, in spite of the fact that in the latter case no provision for the repayment of the original capital is made.

The principle hardly seems sound.

Assuming for the moment that the equated period in the case of the loans for electricity supply purposes were exactly correct, and that it truly represented the life of the plant, the undertaking at the end of

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the equated period would be free from debt by the operation of the sinking fund, and would be then in just as good a position from the ratepayers' point of view as it was when the undertaking was first begun.

A local authority's undertaking may be likened to one owned by a statutory company consisting of seven original shareholders who put up the sum necessary to obtain their Parliamentary powers, and who, having obtained these powers, raised the whole of the capital necessary to carry out the undertaking in the form of debentures repayable at the end of twenty-five years, the interest and repayment in respect of the same being personally guaranteed by the original shareholders.

The seven shareholders in such a company would be in very much the same position as the ratepayers in the case of a local authority's undertaking. Any losses in working would fall upon their shoulders and any profits which remained after paying the debenture interest and after setting aside contributions to a sinking fund for the repayment of the debentures, would go into their pockets.

In the case of such a company it would hardly occur to the seven shareholders, in addition to their sinking fund instalments, to put aside what profit they might make to a reserve fund until it had amounted to the full amount of the capital which had been lent them by the debenture holders.

So long as the shareholders maintained their undertaking in working order and in the position to earn them dividends till the end of its life, they would be content to leave the future to take care of itself, though it is probable that the shareholders, being personally liable for any losses, would take the precaution of providing a reserve fund as an insurance against losses which might be incurred in future working.

The shareholders would surely not deem it incumbent upon them to set aside from their profits a sum sufficient to enable them to continue their undertaking when their plant was worn out, without raising further capital by means of debentures. If their undertaking had been a success, and if their credit were not impaired, there would be no reason why they should not borrow the further capital necessary to replace their worn-out plant and so be enabled to continue the undertaking on the former lines.

If this point be conceded the whole question as to the proper provision for the future in the case of local authorities resolves itself into a determination of what the amount of the reserve fund set aside by our seven shareholders should be.

The question may be asked: Why is it necessary to consider undertakings owned by local authorities on a different basis from those owned by companies? If the sinking fund payments be regarded as part of the contributions to the depreciation and reserve funds, the two classes of undertaking might surely be considered together.

The question, however, does not present so simple an issue as this, since, in the case of local authorities, the period for the repayment of loans is an equated one, and does not actually represent the period

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of time during which the whole of the "plant" used in the undertaking will continue in proper working order, though efficiently maintained.

Certain portions of the plant have shorter lives than others, and when they are worn out it is necessary to incur further capital expenditure in order to replace them.

As, however, the sinking fund remains intact until the end of the equated period of twenty-five years, no portion of it is available for the renewal of the short-lived portions of the plant when they are worn out.

We have carefully to consider what effect these circumstances have on the building up of the depreciation fund: should it make provision for the renewals of the short-lived portions of the plant in order to avoid the necessity for incurring fresh indebtedness before the original loans had been repaid?

In this connection it must be borne in mind that although this difficulty arises in the earlier years under the system by which an equated period is given for repayment of all the capital expenditure, nevertheless, a corresponding advantage is gained in the later years of the undertaking subsequent to the expiration of the equated period. The life of certain of the assets is considerably greater than the equated period of twenty-five years, so that after the expiration of the twenty-five years the total capital expenditure on this class of expenditure has been entirely wiped off, while no necessity arises for further capital expenditure in this direction till a later period.

In the hands of a company the sinking fund provided out of profits would without doubt be drawn upon for the purpose of renewing any portion of the machinery and plant that may have worn out; but this is not possible in the case of a local authority, whose sinking fund is earmarked for the purpose of the liquidation of a special loan.

If any particular portion of the plant had only a life of ten years, and was provided for by a ten years' loan, it is obvious that at the expiry of the ten years and the wiping off of the original loan an amount could be re-borrowed to provide the new plant. The tendency of the Local Government Board is to divide up the loans into periods of life, and when this is done universally all will be plain sailing. In the meantime the difficulty arises in the case of all loans for equated periods.

It must be remembered that the annual contribution to the sinking fund in the case of equated loans covers the depreciated life of both short and long lived assets, and in my opinion a local authority should be permitted to re-borrow for the replacement of worn-out machinery, apparatus, etc., provided that such re-borrowings shall from time to time never exceed the amount contributed to the sinking fund, and provided that the term of the new loan should coincide with the "life" of the new plant. If this were permitted a local authority would be placed in the same position as a company in respect of its depreciation fund.

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The author's final contention, then, is that a local authority should treat depreciation exactly as a company treats it.

It should set aside annually such sums as, properly invested, will enable it to wipe off the value of the various portions of the machinery and plant at the end of their respective lives. If the loans in respect of such machinery and plant are for periods similar to that of their lives then no further sum need be set aside annually.

If, however, the loans, as in the case of some local authorities in the metropolis, be for a period of forty-two years, whereas the lives of the various portions of the plant are determined at say:—

£20,000 in 60 years
£30,000 in 25 years
£10,000 in 15 years
£10,000 in 10 years

then the annual instalments should be such as would produce the various capital sums at the ends of the respective periods. The actual contributions to the forty-two-year sinking fund would be treated as part payments, and it would be necessary to set aside annually a further sum to bring the contributions up to:—

Sinking Fund Payments @ 3%.

		In respect of the
£122	... ...	£20,000 for 60 years
£822	... ...	£30,000 for 25 years
£538	... ...	£10,000 for 15 years
£872	... ...	£10,000 for 10 years
£2,354		

Residual Values.

To arrive at an absolutely accurate amount of annual contribution to a depreciation fund it would be necessary to determine the residual value of the machinery, apparatus, etc., at the end of their respective lives. In the case of land it, of course, remains, and the scrap value of machinery, apparatus, mains, etc., containing a fair amount of copper and other metals, is appreciable. As, however, a depreciation fund must in its nature be based upon an estimate, it has seemed to the author wise to regard the residual value as an item which the undertaking would have to the good at the end of the respective lives, and one which to that extent would be in hand as a contribution towards the cost of new plant.

Discussion.

Mr. Matheson.

Mr. Ewing Matheson: I do not agree altogether with Mr. Hammond's paper, and the fact that I am not in perfect accord with him will perhaps enliven the meeting. Although I am not an electrical

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Mr. Matheson.

engineer, I have at the present time the control of very large electrical undertakings in the country where the financial question is an important one. However, I think I can discuss some aspects of this paper which do not deal with the technical details of electrical engineering. First of all, there is the difficulty at the very beginning of defining what depreciation means. There I differ from the author, because he implies, and to some extent says plainly, that depreciation is some indefinable wearing out of the machinery, such as abrasion, or the wasting away of the boiler, and that contingencies of this kind have to be treated separately from such reserves as the provision for accidents, for a sinking fund, and for an antiquation fund—a word we do not find in our dictionaries—which has to be created for the

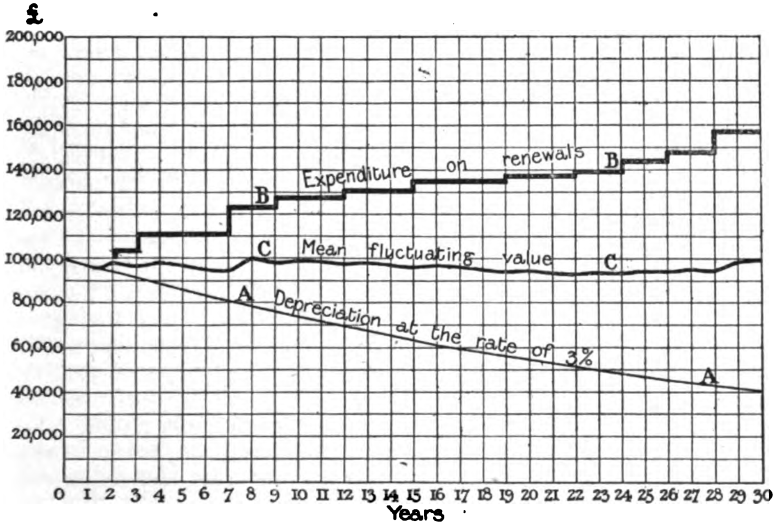

FIG. A.

occasion. I take it that depreciation is a convenient word to sum up all those forms of reserves, or savings, or thrift which are taken out of gross earnings to provide for an unknown future. That is how I have treated it for many years in other kindred concerns which I have had to do with in providing for depreciation. It is hardly ever found that machinery wears out in the way that is anticipated. I am afraid we cannot make a generating plant, and arrange that it comes to its end just at the time that the loan ends. We are continually being asked as engineers to tell the accountant what the life will be, say, for boilers, and for other distinct items. I admire the courage of the author in setting forth a list of categories and periods on page 272, and I venture therefore to show a diagram illustrating my own views. The principle I have gone on, not merely for electrical matters, but with machinery of a kindred kind in engineering work and plant of various sorts, is to show that the

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Mr. Matheson. depreciation is not necessarily a fund that should be put by or invested. It is continually being spent, it is being put into your business.

The diagram Fig. A is based on an actuarial calculation of a depreciation fund at 3 per cent. The lower line A A shows the effect of the depreciation fund of £100,000, writing off 3 per cent. on the diminishing value. That is to say, it goes down to £97,000 the first year; then 3 per cent. is written off the £97,000, so that at the end of thirty years it will be £40,000. My own opinion with regard to machinery and buildings put up nowadays is that £100,000 worth would not be worth £40,000 in thirty years. We will assume for the moment, however, that 3 per cent. is enough for the first two years. That is all savings; it is put by in the books—that is to say, it is money that has come in and not gone out. At the end of two years we begin to spend something; we find, notwithstanding the original newness of the plant, that something new has to be bought either for renewal or replacement. The line B B shows such expenditure in actual pounds; it is an exact record, while the lower one, A A, is an imaginary curve. We know exactly to a penny what we have spent, and year by year it goes on increasing. This new outlay or capital investment continues for some years, and then it will be found in occasional years that there is a big expenditure. Something has gone wrong; something serious occurs; a new cylinder or a new dynamo has to be put in or an entirely new kind of boiler, which means a considerable expenditure. So it goes on varying year by year to the end of the thirty years. The mean value at any time is the irregular line marked C C. It will be observed that the curved depreciation line A A is bringing it down, and the expenditure shown by the line B B is dragging it up. So, according to my theory, at the end of thirty years the assets are worth just as much as they were at the beginning; that is to say, out of earnings or gross profits, 3 per cent. has been provided, and that 3 per cent. has exactly balanced what has been spent. The plant is in good working order, and not only so, but with a bigger earning power, for it has been increased. We have a better plant than we started with, for it is more modern and it will give a greater output. It is worth more to a man who is paying a rent for it, and who has no concern with the future; but it is not worth more to the capitalist, because much of it is half worn out. It has that curious effect, that the rental value of it, and indeed the rateable value, are greater at the end of the time, if the plant has been properly maintained, than at the beginning. The 3 per cent. may have to be 4 or 5 per cent. if it is necessary; nay, in some highly speculative trades it may require 10 per cent. I include everything—I provide for the antiquation, for the unknown contingencies, and for absolute accidents. We must remember there is no insurance society which will insure the antiquation risks of electrical machinery. We have to provide something; we cannot estimate the amount exactly, but can only use the experience of past years, and arrive at it as nearly as may be. In the case of the big works that have existed for many years—the iron works at Manchester, Sheffield, and Middlesbrough—it is only by

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setting aside of liberal reserves that they have been enabled, when a new improvement becomes necessary in the process of making iron or steel, or machinery, or generating electricity, to have a fund on the books that enables them to adopt it. Mr. Matheson.

I would like now to turn to the table which the author has given us on page 272. I begin at the first item: land and buildings. I was distressed when the author pushed that item aside as a matter of smiling unconcern. He said that land cannot deteriorate; it will not run away. It seems an audacious thing to say about land, but in my opinion it can deteriorate in value. In Leeds there used to be a large flax industry; there were huge buildings with large chimneys; but now for years they have been left vacant, and when the time comes and the owner wishes to realise their value, it will cost a great amount of money to pull down the chimneys, to remove the massive foundations, and to render the land available even as agricultural land or for general building purposes. Land is liable to these vicissitudes. It is no doubt a remote contingency, but as regards buildings it must be remembered that while in a church, or a town hall, or a big building, the solidity of the brickwork has only to be considered, antiquation comes into question in all industrial buildings. How about, for instance, a power house that was put up twenty years ago for big, slow-running engines, or with rope gear, and which now has to be altered for putting in turbines? The solid machinery, the masonry foundations which would come in under Mr. Hammond's term buildings, and the chimneys which have to be pulled down, all have to be considered. I say they are not worth sixty years. I do not think it is a fair way to lump the land and building together. I will not presume, in an audience of this kind, to deal with the question of purely electrical machinery. With regard to boilers, I am now pulling out magnificent boilers, which are good to-day for 160 lbs. working pressure, in perfect order, made by the best makers. I am not scrapping them because I am selling them, but I am not getting half what they have cost, including foundations. They are being scrapped, however, in the sense that they are being discarded, and the cost of getting them out and carting them away is considerable. Therefore even in boilers the question of antiquation and renewal comes in. Then, we all know the early rubber-covered mains have had to be taken out and all the accessories rendered valueless. I have heard no evidence whatever that the modern mains are not permanent, but even so it is rather a fallacy to assume that they will last, because there may be a change of system. Here again I am trespassing on what is to me somewhat forbidden ground, because I do not know what improvements may be in store; but I would suggest to this audience that there may be new means of conducting electricity, new systems of cable discovered (we have had indications of that during the last twenty years), so that the question of replacement as well as maintenance comes in there also. Although old copper commands a good price, it would not pay for the new mains. It may be said there is enough margin left there, but I think all these estimates

Mr. Matheson.

given by the author are rather too liberal. I take it that the gentlemen in this room are all interested as purveyors, manufacturers, or engineers, and not as consumers. I would say to those who have the control of electrical works, do not be in a hurry to reduce your prices and to give anything to the public, or to pay too big dividends. Retain all the money you can and put it by; disguise it if you like in your books, so that you have a saving that you can use. There is another thing to be taken into consideration in regard to the wear and tear of electrical plant as compared with other plant, and that is where there is spare plant which may be idle. It does not wear out in the period in which the other, say nine-tenths, wears out, but it shares the same fate of the other engines in being antiquated. If a plant which is working all day and night gets antiquated, the other plant that is kept fresh and clean which has hardly worked at all will be antiquated too, although some of the scrapped plant may be perfectly worn out. In regard to the depreciation provided for maintenance, the author said antiquation was a separate matter, but in my view that is part of the depreciation. I do not mean little things like fire-bars, or brass-bearings, or anything of that kind; I mean such a thing as a new cylinder, or even a new piston, or new dynamos, or rewinding. The outlay for these would be part of the expenditure shown on line B of my diagram. According to my theory the money would be spent as there set out. We are collecting it on the line A A, and are spending it on the line B B, and there the two balance and produce the line C. It seems to me in providing a depreciation fund that is what should be aimed at, always with the proviso that the assumed rate of 3 per cent. may be altered to 2 per cent. or 5 per cent. The author says it is not necessary to have a renewal fund as well as a depreciation fund, and I agree with him. To me one is the same as the other. Then there is the question whether we should put money into the bank and let it increase, or whether it would not be much better invested in the works. Surely if one has some money it is much better to get 5, 6, or 7 per cent. on it than 2½ per cent. by depositing it in a bank. But if ready money be needed to meet a sudden call, as a life assurance company needs it to meet a year of epidemics, then keep the savings liquid and available. Mr. Hammond winds up by saying that "to liquidate a loan of, say, £100,000 in twenty-five years requires an annual instalment of £2,742 16s. (assuming an investment of 3 per cent.)" What I presume he means is that that sum put aside at compound interest will produce that total at the end of the period. But what about the depreciation and maintenance of the plant during that period? In the sinking fund, which the Local Government Board provides for, we are paying off capital and interest combined, but we have to maintain and renew also. I think, therefore, we want some little further explanation, because it seems to me that page 280 is rather misleading. I do not think the investment plan is often adopted. I do not know anybody who would put by so much money in a bank or in Consols, and invest it at compound interest. It is very pretty as a theory, but I should like to know if Mr. Hammond has done it in any case of his own.

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Mr. HAMMOND: It is absolutely done in the case of your own Leeds works. Mr. Hammond.

Mr. EWING MATHESON: We pay the sinking fund, but we do not ourselves invest it as described in the paper. Mr. Matheson.

Mr. HAMMOND: You have to pay the interest, of course, but it accumulates at 3 per cent. Mr. Hammond.

Mr. EWING MATHESON: I will put it this way. Supposing we borrow £100,000, they say, "If you will pay so much off a year for thirty-five or forty years the thing is cleared." We do not pay a miserable sum and invest that at 3 per cent.; we pay a great deal more, for we have to pay in all 3 or 3½ per cent. interest and the capital also. Mr. Matheson.

Mr. A. A. CAMPBELL SWINTON: There are a great many points in this very interesting paper with which one can agree, but there are others on which one must take the opposite view. The author seems to think that a local authority and a company are so much on a par that depreciation can be arranged for exactly in the same way in the one case as in the other. I would like to point out one great difference that exists between them. In the case of a company nobody is obliged to become a shareholder. Any one who does so does it at his own risk; the shareholders pass the accounts, and if they do not think that enough is allowed for depreciation there is always an opportunity for them to turn out the directors, and put in others who will allow more depreciation. But ratepayers are compulsory shareholders in municipal trading. They have no choice, and they have very little control. It is very nice to arrange these matters upon a pretty theory, but my experience tells me (and I think it is the experience of most people), that it is really necessity that governs these matters much more than theory. People put as much to depreciation as they can, but it is not always as much as they would like. Then there is this further point. In the case of a company that is going after a certain term of years to be bought up by the local authority, every penny that is put to depreciation the shareholders will never get back again. I am not at all sure (having regard to the fact that the accounts are all audited by the Board of Trade) that an arbitrator can very well put the then value under the terms of the purchase-clause of the Electric Lighting Acts, at a less amount than the value of the undertaking as it stands in the company's books. That is a very important question. I know that critics will immediately refer me to the Tramway Acts, and point out that in the case of purchases under the Tramways Acts (electric lighting purchase not yet having taken place under the Acts) arbitrators have put the value at much less. But it must be remembered that the tramway companies' accounts were not and are not audited by the Board of Trade, and that the Board of Trade specially audits these electric lighting and supply accounts, not in the interests of the shareholders of the companies, but in the interests of the general public and of the local authorities who are going to purchase. There is also a very considerable difference in the wording of the Clause denoting the terms upon which the purchase is to be made in the two instances. In both Mr. Swinton.

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Mr. Swinton.

cases it is the *then value*, but in the case of the Electric Lighting Acts circumstances are to be taken into account, such as the fact that the works are in readiness for immediate working, and there are other words which do not occur in the case of the Tramway Acts at all. So that companies, in arranging how much they should put to depreciation, ought carefully to consider the effect that this may have upon the amount of money they will get back when they are bought out by the local authority. In the case of a concern that commences on a fairly small scale and increases gradually, as has been the case in most electric light undertakings, a system that can be adopted is practically the system that is adopted by railway companies, which is not to have a special depreciation fund at all, but to do all renewals out of revenue. If a very large installation is put down all at once, there will come a period when the spare annual income would not be sufficient to pay for the large amount of depreciation that would have to be made good all at one time; but in the case of an undertaking which is built up gradually, it will be found that, as it gets bigger, when the plant begins to wear out, it is only in comparatively small portions at a time which one can conveniently replace out of revenue.

Mr. Sherley-Price.

Mr. H. SHERLEY-PRICE: The question of depreciation is so important that indeed, to some extent, it may be said that our national credit is affected by it, as well as the permanent welfare of most manufacturing industries. Owing to the lavish manner in which municipal authorities have become involved in lighting, tramway, and similar undertakings, representing almost untold millions, which outlay shows little or no resultant profit, the investing public have taken alarm, and now even the London County Council itself, backed as it is by the whole rateable value of London, can no longer obtain money at previous rates of interest. All this doubt and uncertainty arises from the belief that in ascertaining so-called profits, sufficient allowance for the inevitable depreciation has not been made, and that to this extent such profits are misleading.

We are all agreed that there is and must be depreciation, whether in municipal, public, or private hands, and whether considered so or not, depreciation is as much a matter of working expenses or establishment charges, as are amounts paid for rents, rates, taxes, coal, or any other similar items of expense. The question has been raised of including sinking fund with depreciation, and this is, in my estimation, a wrong basis altogether. I do not propose to deal with sinking fund—that is purely a matter of accountancy, and furthermore has already been fixed by Government and cannot, therefore, be changed.

It has been suggested that the correct way to arrive at a rate of depreciation is by estimating the life of the plant dealt with, and if this were easily done there would be no further difficulty in the matter, but it is this very fact, namely, the hypothetical life of an object, which it is, I maintain, impossible to fix with any degree of accuracy. I see in the paper a list giving the estimated life of different objects varying from fifteen to sixty years, and on this theoretical basis it is suggested that

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rates can be formed. I venture to think that the experience of all here will show that the rates adopted are much too high—probably from 30 per cent. to 50 per cent. or more, that is supposing they were fairly maintained and no case of obsolescence or accident occurred; but from my own experience in estimating depreciation extending over a period of thirty-five years and covering many millions in value, I must confess that I do not feel myself competent to fix a rate of depreciation to cover more than a short period, and whatever rate may be fixed, it is one which is apt to be upset by a variety of circumstances beyond control. Mr. Sherley-Price.

Then the maintenance or upkeep depends upon the ideal of the man who works it, it is easy to presume that all will be kept in going order. But what about supersession by new inventions? I wonder how many thousands of horse-power in the shape of engines and generators have been thrown out during the past two years which were not ten years old, and, indeed, how many similar sets are there at the present moment in the market for sale at a low price, not from depreciation by actual use, but from obsolescence?

It is impossible, in my opinion, to construct a diagram or to reduce to scale by varying percentages, a scheme that will cover depreciation such as will justify an auditor in passing it through his profit and loss account.

The only safe way that I know of is to have the plant valued at a given time at its full fair value as a current going concern by an outside expert independent valuer. A fair basis is thus obtained—not one of actual cost it must be remembered, because the cost might have been far too high or, on the other hand, may have been moderately low—the same valuer, if an expert, can then fix a rate that will last probably two or three years and no longer, when it should be again re-valued and brought to its proper value. The best method is that which has been adopted by many of our large engineering firms, namely, to have the same valuer make an annual inspection, which is only a small matter, and this annual inspection can go on for three, five, or seven years, and then an entire re-valuation is made in order to test whether the percentages or allowances made or added have been correctly done. Possibly objection may be taken to this on the subject of cost, but surely the matter is one of such profound importance that the cost, which after all is only very trifling, should not be allowed to stand in the way of having an accurate balance sheet and profit and loss account. It is, in my opinion, wrong to ask either an accountant or a manager or other interested party to fix a rate of depreciation; the accountant has not the technical knowledge, and the manager, being only human, naturally will not put a heavy rate of depreciation and thus reduce his profit.

Mr. W. R. Cooper: I am glad that Mr. Hammond has read this paper before this Institution, for the subject is of the utmost importance, and has not received adequate attention. Very few figures have appeared in reference to the probable life of plant. Some figures Mr. Cooper.

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Mr. Cooper.

were, however, given last year by Sir William Preece in a report to the Bristol Corporation, and as such figures are of considerable value, I venture to reproduce them here (although already published) so that the present discussion may be more complete :—

	Life in Years if Properly Maintained.	Residual Value at End of Life. Per Cent. of Original Cost.
Land	—	—
Foundations	100	nil
Buildings	80	nil
Boilers (water tube)	25	5
Lancashire Boilers	22	3
Dynamos and Alternators ...	30	8
Engines and other Machinery ...	25	6
Cables (armoured)	35	15
Cables (solid in wood trough) ...	40	12
Buildings (sub-station)	50	nil
Sub-station Equipment	25	12
Accumulators	15	10
Arc Lamp-posts	40	5
Arc Lamps	12	5
Motors	25	9
Office Furniture	—	—
Meters	12	2
Accessories and Instruments ...	12	2
Tools and Sundries	10	5
Electric Launch	10	5

These figures refer to an undertaking which was already at work. It will be noticed that some of the lives that are given are longer than those given by Mr. Hammond. For example, foundations are put at 100 years and buildings at 80 years. The life given in the paper for buildings appears to be somewhat short, though, in certain cases, I think that the shorter lives given for other items of plant will be preferred. I would suggest, however, that a definite life cannot be proposed without taking into account the character of the load, and I would, therefore, ask Mr. Hammond whether the lives which he gives are for a lighting load, or for a more uniform load, such as is obtained on traction systems. With regard to the life of accumulators, it seems scarcely rational to consider depreciation on a basis of fifteen years, if this life merely refers to the boxes and connections.

I think there will be a general agreement that short-lived assets should be provided for by local authorities in the way suggested by the author. This method, I believe, is already in operation at Bristol, and should certainly be general. But where assets become of comparatively small value rapidly for some reason or other, it is much more difficult to provide for them, and equally difficult to replace

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them, owing to the attitude taken up by the Local Government Board. As an instance, I might mention the case of a large triple-expansion condensing pump which had been at work for about eight years, and was supposed to be a most valuable asset. Upon testing, however, it was found to be working with a steam pressure of less than 40 lbs. per square inch in the high-pressure cylinders, and frequently with a vacuum in the intermediate cylinders. Consequently, it was highly inefficient, and, in fact, altogether unsuitable for the work. As it became necessary to renew the whole of the remaining plant, which was worn out, it was suggested that this pump also should be removed. But the value of the new plant was about equal to the original loan upon this pump; and, consequently, if this pump had been removed, the Local Government Board would have reduced the loan on the new pump to about half the value or less, which would have made it impossible to put in the new plant. For that reason the useless triple-expansion pump was retained, although it would have made a more satisfactory scheme if removed. There seems no object in the indiscriminate reduction of new loans by unpaid-off parts of old loans, and it places local authorities in considerable difficulties when plant, which has become unsuitable for any reason, ought to be replaced. I think that the point is really sufficiently important for the Council of this Institution to take the matter up with the Local Government Board, with a view to obtaining a more reasonable attitude. Mr. Cooper.

Mr. W. W. Cook: In making provision for depreciation, there are always two parties concerned—the engineer and the accountant; the first to settle what the amount of depreciation is, and the second to see that the necessary provision is made. To-night we have had the accountant's side put before us more than the engineer's. Mr. Cook.

The accountant is not so much concerned with the exact method of providing for the depreciation as he is with the result, and the effect of any error on his part is only temporary, and does not inflict loss on a permanent shareholder, as it can be rectified; but the exact method is very important to the engineer, because he has to make a choice between alternative types of apparatus, which may be very largely affected by depreciation and the exact method of calculating it. If he makes a wrong choice, money is absolutely wasted.

Some previous speakers have dwelt on the difficulty in forecasting lives, and I am sorry to see that the author does not consider it necessary to allow for the residual value, but there is no alternative; the life has to be fixed as well as the residual value before any intelligent decision can be arrived at.

Take the case of a choice between two machines, either of which will do the work equally well, one of which costs £100 and will last for fifty years, and the other costs £30 and will last for ten years, the maintenance being equal in both cases, and the residual value of each being 10 per cent. of the first cost. If we employ a method which ignores interest on the sum set aside annually, like the first method described by the author, we shall find the £100 machine appears to be

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Mr. Cook. the best investment; but by using a method which takes interest at 5 per cent. into account, the £30 machine will come out cheaper as it really is, so that it is highly important to use a correct method.

Mr. Dykes. Mr. A. H. DYKES: There is one point that occurs to me in connection with the depreciation of batteries. It is a subject on which I have had some slight controversy with auditors, and also with the mythical gentleman known as "Mr. Chesterfield, jun." Some companies are in the habit, instead of putting by a sum each year for the depreciation of their batteries, of paying a maintenance charge to the makers, for which sum the latter agree to keep the batteries at all times in good working condition and repair, and renew, as may be necessary, free of cost to the purchaser. In more than one company in which that has been done, the question has arisen as to where this payment is to be put. The auditor in one case said it was an insurance, and should be put under that head; another took the standpoint that it should be under Repairs and Maintenance, the result being that the repairs and maintenance on the batteries looked exceedingly high; but, as during those years not a penny had actually been spent on repairs and maintenance of the batteries, it does not seem to me it is a repair item at all. In my view it should be properly a depreciation item, and, therefore, supposing one pays £100 per annum for the upkeep of batteries—that is, £100 contributed towards the depreciation account—one is entitled to credit the depreciation account by that amount of £100. It is obvious that, as the makers will go on as long as one likes keeping up the battery to the full capacity for this sum, at the end of ten, twenty, or thirty years the battery is as good as it was to begin with, and, therefore, it is not fair that one should be called upon to provide an additional depreciation account on the batteries, in addition to this sum which is already being paid as a battery maintenance. From the engineer's point of view, in one case there is a large item for repairs and maintenance, and nothing put to depreciation; whereas, looking at it the other way, the amount for repairs and maintenance is lower, and a contribution is made towards the depreciation account. It seems to me it should go to depreciation, and be credited as a contribution toward depreciation. If, instead of paying the agreed sum each year to the makers, it were put to the depreciation account and invested, when the battery wore out the money would be there to buy a new one with, and it would properly be called a depreciation item. I contend it makes no difference as regards its being a contribution to the depreciation fund if it is paid over each year to the battery maker to invest for one.

Mr. Watts. Mr. A. WATTS: I must confess having been rather disappointed with the paper, and especially that such an able exponent on depreciation should have confined himself almost to the fringe of the matter, and only given us just sufficient information to convert the local authorities or the Local Government Board—I am not quite sure which —to his own way of thinking. The paper is somewhat unfortunate, as it conveys the impression, to my mind at any rate, that the question of

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depreciation and the life of the plant is only brought under consideration when the profit-earning stage is attained. I think this is altogether wrong. The view I take is that, before any scheme involving the putting down of plant is recommended by an engineer, the life of each part of the plant should be considered, and a serious estimate made as to the life of the whole system; the amount of depreciation to be set aside each year then follows as a matter of course. With regard to the treatment of residuals, mentioned by the author at the end of the paper, I do not agree with the rather summary way in which he deals with that quantity, because an estimate must be made as to what their value is going to be before it can be determined what is the proper plant to put down. If we have to choose between two classes of plant, it is necessary to decide which is the more economical, and to do so the residual values must be brought into the balance. Taking mains as an example, these make up a considerable percentage of the total expenditure of an electricity supply. In the table on page 272 we get a life of thirty years given indiscriminately to mains laid in ducts and mains laid solid; this would almost invariably lead to a solid laid cable being put down. I am not quite sure of the figures, but I should say it would be from 10 to 20 per cent. cheaper than a cable drawn into a duct. For the sake of illustration we will take it as being 10 per cent. cheaper. Then if we spend £1,000 on a cable laid in ducts as against £900 for a solid laid cable, the amount to be set aside for depreciation is, in the one case, £18 odd per annum, and in the other case £21—a result in favour of the solid system. But by bringing into the balance the residuals of the cable which can be drawn out of the duct at the end of the period, which will be something like 25 per cent. of the value of the cable in place, and deduct that from £1,000, it leaves a balance of £750 on which we have to provide depreciation at 3 per cent., reducing the annual charge on the cable drawn into the duct to £15·7 per annum, a saving of something like 16 per cent. in favour of the cable drawn into the duct, an entirely opposite result to the one obtained in the first case by comparing the two things on the basis as laid down by the author in the paper. To put the case another way, in making a comparison between the two systems, £1,000 might be spent on a duct system, and give an annual cost equal to £750 spent on a solid laid cable. The life also appears to be somewhat short. Then with regard to the point as to whether the sinking fund should be one outside the business or in it, I think it depends largely on the class of business. If we are dealing with a business in which the capital account is closed, I think it is reasonable and good finance to invest the depreciation fund outside. On the other hand, if it is an Electricity Supply Works, one is spending money every week (every day almost) in making extensions, and although it may be sound finance it does not appear to me to be good business to be borrowing money at one rate and to be lending it at a lower rate in connection with the investments. Mr. Watts.

Mr. JOHN PLACE (*communicated*): In this paper the author has introduced many interesting points, and certainly some which will raise a Mr. Place.

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Mr. Place. good deal of controversy. It can hardly be said, however, that all the matters put forward could be adopted as tenets, in fact it would be dangerous to do so. The paper itself treats depreciation on far too broad lines, and also seems to have got into the groove which one may perhaps define as the "accountancy" groove. In other words, the depreciation is supposed to account not only for a fund which is to cover the sums borrowed, but also under the same heading to cover the dwindling value of the plant, machinery, etc., involved, and in doing so it practically resolves itself into writing the value of these physical objects off according to rates which are to be standardised and used, irrespective of what the plant is and how it is maintained. To say that engines have twenty-five years' life, and are therefore to be written off yearly at the rate of 4 per cent., is very wrong; the same applies if one wants to fix a life for any other machinery or plant. No two stations or manufactories will keep their plant up to the same degree of efficiency, and this being the case, how can a standard depreciation be adopted? Even if certain standards were adopted, there would be great chance of them being wrong in themselves, for no accountant could fix the proper initial cost of the item in question. It is well known that in many cases money is expended without any thought of economy, and if this expenditure were taken as the basis on which to write off or depreciate, it would in principle be wrong. In dealing with the question of depreciation generally when applied to manufacturing concerns, at least two things are to be taken into consideration, and these two may be defined as belonging in the first case to the "accountancy" side, and in the second case to the "mechanical" side; that which is treated by the accountants need hardly be discussed here, for the way in which the loans are to be written off is one that is A B C to the accountant, but it is far different with the machinery. Here the accountant is quite out of his province if he tries to fix a standard rate at which to depreciate the physical objects—this can only be done by an inspection of qualified engineering valuers. Many firms adopt this means, and have their plant, etc., valued, and afterwards an annual inspection made in order to fix rates of depreciation, which are dependent upon the state in which the machinery is found at the date of inspection. These rates may, and can, apply for several years, and at the end of this a re-valuation should take place, in order to adjust matters and to see whether the rates, which have been in the interim applied, still hold good.

The whole gist of these remarks may be summed up shortly as follows: That it is dangerous and imprudent to couple the depreciation as allowed by accountants with that which should be allowed on the plant, machinery, etc., and that this latter cannot be fixed by any rule, but must be applied on close investigation and examination on the spot in a manner in which many industrial concerns are now adopting.

Mr. Parsons. Mr. T. C. PARSONS (*communicated*): There is a point which the author mentions on page 275 which is frequently lost sight of both by the auditors of municipal accounts and by some councillors, namely:

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Mr. Parsons.

That there is a difference between depreciation by a company and by a local authority, in that when the local authority writes off capital the money goes out of the business altogether.

The proper way of looking at depreciation by a local authority, to my mind, is that such a sum should be added to the renewal fund, which added to the sinking fund and taking into consideration the residual value of the plant, will at the end of the estimated life of the plant be equal to the original expenditure on that plant; so that assuming for the sake of argument that all the plant gave out suddenly at the end of the estimated life, the local authority would have no assets and no liabilities. If a local authority does this it just scrapes through, as it were, and should, I think, add all its net profits to such a fund until it reaches 10 per cent. of the capital, and after that to write down its capital if it is deemed desirable.

I quite agree with the author that it is not sound to expect a local authority, in addition to its sinking fund, to provide out of its revenue or the rates a depreciation fund which will enable new plant to be bought at the end of the period of the original loan without raising fresh capital, and I do not know that it would be legal to depreciate in this way out of the rates. This is not done in any other branch of municipal enterprise, and it is difficult to see why it should be done in connection with electrical undertakings.

If the method of arriving at the amount of depreciation which Mr. Hammond sets forth in his paper is accepted, the question then turns entirely on the length of the estimated life and the residual values of the plant, and Mr. Hammond's figures for the life are, I think, well on the safe side.

Some few months ago I had to make a report to my committee on the subject of depreciation, and got a good many figures with regard to the life of plant. I found that in a good many cases boilers put down twenty to twenty-five years ago were still working at the original pressure, and were being passed as satisfactory by the insurance companies. Cables which had been laid fourteen to eighteen years were still quite good. Dynamos and motors, which are still running after twenty-five years, and many other instances all going to prove that Mr. Hammond's figures cannot be accused of being too favourable.

It is, I think, only reasonable to believe that if the machinery made twenty years or so ago is still in good condition, that which is being made now, with all the additional experience manufacturers have gained, will at least last as long.

I think the following figures may be taken as safe for life and residual value :—

	Life.	Residual Value.
Machinery	27	6 per cent.
Accumulators	15	10 „
Mains	30	15 „
Motors	25	9 „
Meters	12	5 „
Instruments	12	5 „

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Mr. Parsons. With regard to the question of obolescence, I do not think that it is such a very vital one with the more modern stations. Assuming that the system of distribution is not changed, we cannot expect to get very much more efficient plant than that which is running in many modern stations, and any possible gain in efficiency by using the very latest types of machinery would not be compensated for by the capital value of the existing plant, which would practically have to be scrapped.

Mr. Bowden. Mr. J. HORACE BOWDEN (*communicated*): I note in the first proposition in his opening remarks, that Mr. Hammond assumes a life of twenty-five years for machinery, apparatus, etc., costing, say, £100,000, which, if invested in the undertaking, would necessitate the provision of an annual sum of £4,000 for depreciation, but on the other hand, if invested in securities at 3 per cent., would only require the provision of an annual sum of £2,742 16s.

In the first instance, Mr. Hammond states that the book value would be reduced to nil at the expiration of twenty-five years. I think he must have overlooked the fact that if invested in the undertaking, for machinery and apparatus, the book value would still be £100,000.

In the second instance, I suggest that the principle is wrong, as at no period until the expiry of the life of twenty-five years would sufficient provision have been made, which certainly is not sound finance.

The table on page 295 illustrates the difference between the two systems during the various stages of the life of the assets.

From the above statement it will be clearly seen that in the event of a realisation of assets at the expiration of, say, twelve years, the depreciation fund in the second instance would be £9,000 less than it would have been if the first system had been followed out. I am certainly of the opinion that the full provision should be made annually, whether invested in the undertaking or in securities, but if in the latter, the interest on the investment should be placed to revenue account, in order to meet the interest on further issues of debentures. I presume that the rate of 3 per cent. is merely figurative, and that in actual practice a company would invest at a similar rate to the interest paid on their own debentures, which course, if adopted, would place both systems on a financial level.

I take it that Mr. Hammond's estimate of the various "lives" is merely for the sake of example, but I trust that, from the discussion which it will undoubtedly incite, the outcome will result in the formation of a fixed standard of depreciation of electrical assets, under the auspices of the Institution of Electrical Engineers, and which will be made compulsory by the Local Government Board and the London County Council.

I am at a loss to understand why Mr. Hammond places the life of turbines on a lower estimate than reciprocating engines, for, if we believe the statements of the turbine builders, the wear and tear is considerably less than is the case with engines. It would also be

Mr. Bowden.

Invested in Undertaking.			Invested in Securities.		
Year.	Annual Sum.	Provision to Date.	Year.	Annual Sum.	Provision to Date.
	£	£		£	£
1	4,000	4,000	1	2,743	2,743
2	4,000	8,000	2	2,825	5,568
3	4,000	12,000	3	2,910	8,478
4	4,000	16,000	4	2,997	11,475
5	4,000	20,000	5	3,087	14,562
6	4,000	24,000	6	3,180	17,742
7	4,000	28,000	7	3,275	21,017
8	4,000	32,000	8	3,373	24,390
9	4,000	36,000	9	3,474	27,864
10	4,000	40,000	10	3,579	31,443
11	4,000	44,000	11	3,686	35,129
12	4,000	48,000	12	3,797	38,926
13	4,000	52,000	13	3,911	42,837
14	4,000	56,000	14	4,028	46,865
15	4,000	60,000	15	4,149	51,014
16	4,000	64,000	16	4,273	55,287
17	4,000	68,000	17	4,401	59,688
18	4,000	72,000	18	4,534	64,222
19	4,000	76,000	19	4,670	68,892
20	4,000	80,000	20	4,809	73,701
21	4,000	84,000	21	4,954	78,655
22	4,000	88,000	22	5,102	83,757
23	4,000	92,000	23	5,255	89,012
24	4,000	96,000	24	5,413	94,425
25	4,000	100,000	25	5,575	100,000

interesting to know Mr. Hammond's opinion on the depreciation of spare parts. Should these be included in capital in the allocation of the plant that they are subsidiary to, and thus depreciated in a similar manner? Certainly spare parts should not be provided out of revenue, as at present insisted upon by the sanctioning authorities. I would also point out that land rarely depreciates but more often considerably appreciates, and that no provision should be deemed necessary under this heading.

Mr. Hammond's list of "lives" is too long, and would involve a tremendous amount of clerical labour to carry out. The system would be equally efficacious if the various items were allocated under general headings, and the "lives," under each heading, equated.

In considering the necessity for a general reserve fund, in addition to adequate depreciation, I do not think it wise to pass from it so lightly. If we are to insure against all emergencies, it will be found most difficult to draw the line of demarcation between unavoidable accidents and those resulting from carelessness. From experience I have found that compensation generally ends in compromise, and the

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Mr. Bowden.

result is never satisfactory. Insurance should be curtailed as far as possible with safety to the undertaking, and the reserve fund built up in such a degree as to include provision against the antiquation of plant, etc.

I notice that Mr. Hammond does not propose (and rightly too) to carry to sinking fund any fluctuation in the value of materials, such as copper, etc., this adjustment being made on the residual value of the assets.

It is indeed refreshing to read that local authorities' undertakings as a class are not, in the author's opinion, in an unsound, bad, and generally noncommercial state, which seems to be the predominating idea at present. I am certainly in agreement with Mr. Hammond that depreciation further to the compulsory sinking fund is necessary in the case of local authorities, more especially those in the metropolitan area, and I would submit the following suggestions to be followed by such, namely :—

1. That a capital limit be fixed for each undertaking, which must not be exceeded unless the sanctioning authority deems the demand of the area warrants same.

2. That the normal expenditure on account of capital must not exceed the amount provided for sinking fund.

3. That the sinking fund be composed of redemption, plus an amount necessary to raise it to depreciation, based on the standard life of each class of asset.

4. That the reserve fund should provide against replacement of plant before the expiration of the standard life.

The amount required from this fund would be the original cost of the asset, less the amount provided by sinking fund, and the residual value of same.

Provision against all extraordinary expenditure not covered by insurance.

Provision for a working revenue balance.

5. That interest on sinking fund investments be credited to revenue account, so that in no case will the revenue be charged with more interest than that necessitated by outstanding debt.

6. Absolute unanimity on the point that undertakings are only expected to be handed down to posterity at the then value, neither relieved of debt, or on the other hand, overburdened by obsolete capital expenditure.

Discussion by the Dublin Local Section.

Dublin, May 2, 1907.

Mr. Brew.

Mr. W. Brew: I would draw attention, in the first place, to the difference between municipal and company finance. An actuary divides accounts up into liabilities and assets, the plant being regarded as assets and the wages, coal etc., as liabilities. The value

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of the assets diminishes at the expiration of each year, and such diminution is met from revenue account. With a municipality, however, the matter is entirely different; the Local Government Board allows loans for stipulated terms of years. A company has to pay only interest and depreciation, whereas a local authority must both pay interest and redeem the capital expended at the expiration of the period for which the loan was granted. Four per cent. per annum as depreciation on undertakings of this nature has been suggested recently before a Parliamentary Commission, and what would be the effect upon existing undertakings if this basis were generally adopted? Take, for instance, Portsmouth. The gross profit for the year ended March, 1906, was £28,630 on an invested capital of £295,036. Interest and sinking fund absorbed £16,806, leaving a surplus of £11,824; but had the accounts been debited with a charge of 4 per cent. on the capital as depreciation there would have been only the small profit of £22. Supposing this method to be correct, what would be the position at the end of twenty-five years? If the original plant were entirely worn out a new one could be put down, and from that time the undertaking would only have to provide 4 per cent. annually for depreciation—a truly rosy state of affairs, but scarcely fair to present-day consumers and ratepayers. Mr. Brew.

The question of depreciation is further complicated by the variation in the scrap value of the plant with the metal market fluctuations. Within the past few years copper has risen in price about 54 per cent., lead 44 per cent., and iron 20 per cent. The net result of this rise in the price of raw materials will increase the cost of an average 3-phase cable system of distribution laid solid in iron troughing by about 23 per cent., and it appears that the dictates of sound finance would point to an annual valuation of the plant and mains rather than to the adoption of a fixed annual decrement to provide for depreciation. As regards antiquation, I certainly think it necessary to provide for it. Improvements are constantly being made. As an example, transformers of 100 k.w. rated load a few years ago required 1,200 magnetising watts; now they can be purchased for about £1 per kilowatt, with an open circuit loss of only 600 watts. Assuming the cost of energy to be 1.5d. per unit, there will be a saving of £32 16s. per annum by substituting new transformers for the old ones whilst still paying interest and sinking fund charges upon the old and new transformers. In fact, in many cases it will pay to replace the old transformers should the cost of magnetising energy be as low as ½d. per unit. In my opinion an intermediate stage should be adopted, and a depreciation account opened as soon as the department is in a position to pay depreciation. At present many such concerns cannot pay interest, sinking fund, and depreciation as well.

Mr. W. J. SOWTER: I do not agree with Mr. Brew's supposed saving in the example he has given concerning transformer losses. I should regret it very much if it cost the Dublin Corporation 1½d. per unit for magnetising current, but I do not believe it does; in fact, I imagine Mr. Sowter.

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Mr. Sowter.

that if a would-be consumer approached the Corporation, and offered to take current steadily for twenty-four hours per day at 1½d., they would jump at the offer! I agree that it is essential that a depreciation fund should exist in connection with every municipal undertaking. It is an extremely difficult matter to determine the average life of plant, because so much depends upon how it is treated during its life, and the amount expended in repairs. If parts were renewed from time to time, I imagine an engine would last for ever, therefore the repairs account is really a depreciation account. It is, of course, not sound engineering to maintain plant in this way, because, with the evolution of time, things change, and in order that electricity supply may be a success, it is essential that every improvement should be taken advantage of in order that we may be able to compete on equal terms; therefore I consider such funds should be available, but more for the purpose of replacing obsolete plant than for pure depreciation.

Mr. Pilditch.

Mr. G. F. PILDITCH: I do not agree as to the necessity of providing depreciation funds if the plant is efficiently maintained out of revenue, and interest and sinking fund are paid, that is sufficient. It would be unfair to present ratepayers to give their successors a brand new plant at the expiration of twenty-five years. Loans should be raised in accordance with the estimated life of the plant, and when the loans have been extinguished fresh ones should be entered into *ad infinitum.*

Mr. Kinsey.

Mr. A. T. KINSEY: The author has done well in estimating an extended life for the plant. Inspection was invited during the International Engineering Congress at Glasgow in 1901, of a case in which an engine and boiler had done good service for forty years. I also think that allowance should be made for the residual value of the mains at the end of the equated period. As a matter of fact, some mains have appreciated since being laid, owing to the heavy rise in copper.

Mr. Ruddle.

Mr. RUDDLE: I believe that as early in the life of an undertaking as is practicable a renewals fund should be started. Improvements are continually coming forward which have to be adopted. I consider Mr. Hammond's estimate of life of plant, etc., fairly correct, although it is not always wise to stick to it. I consider that the Local Government Board should grant loans for each item in accordance with its estimated life, so that fresh loans could be obtained for renewals when the original loan had been paid off for each section, instead of having to wait for the termination of the equated period over the entire plant.

Mr. Kettle.

Mr. L. J. KETTLE: I think we all agree that in the case of an equated period loan it is not only advisable, but necessary, to set aside a depreciation fund to provide for the renewal of the shorter-lived portions of a mixed generating and distributing plant. I would, however, substitute "antiquation" for "depreciation." If the worn or damaged parts of an engine plant be replaced out of the repairs and maintenance account the plant's life may be almost indefinitely extended, but a time will, of course, come when it has become so hopelessly antiquated that it must be scrapped.

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Mr. Hammond.

Mr. R. HAMMOND (*in reply*) said: I much appreciate the remarks of Mr. Watts; and I thoroughly agree with him. The paper is truly described by him as dealing somewhat with the fringe of the subject. I have been contented in writing the paper to be suggestive. It is urged that I seem to have limited myself in the paper to an endeavour to persuade the Local Government Board to take a particular view of local authority loans. I am sure when Mr. Watts reads the paper over again—if he will kindly favour me by doing so—he will find that I do not quite limit myself to that; indeed, I think Mr. Campbell Swinton's remarks stand as strong evidence against him. Mr. Campbell Swinton was induced by the paper to rise as the champion of the company view, and I am sure he would not have worried his head at all if it had been simply a question of a little bit of local authority business.

If the paper has done nothing more it has provoked a discussion on one or two points which I think are of vital importance to the industry. I entirely agree with Mr. Watts that no depreciation fund is logically sound that disregards the value of residuals. I trust Mr. Watts, as well as myself, will live to see the day when we are all so agreed upon the life of electricity plant that we shall be able to map it all out, weigh in the residuals, and do everything as if we were dealing with bank-notes and sovereigns. But in the meantime we have the evidence of Mr. Matheson that it is so difficult to foresee future values. In Mr. Matheson we have one who is the chairman of one of the most important local authority undertakings in the country, and who says that somehow or other he fears that his plant may all be antiquated in a few years, and that we might wisely only allow four or five, or perhaps six years' life for some of the plant. We should all be in a very bad way if we worked on those principles, because consumers do not exist who would support an undertaking with such a burden upon it. I draw Mr. Watts' attention to the fact that I did say with regard to depreciation that we had to face it whether we were working at a profit or a loss. At the top of page 274 I pointed out that the very first charge upon an undertaking, after its working expenses, is depreciation. In the event of the working showing a loss for some years we have, before we begin to say we are making a profit, to make up that depreciation fund to what it ought to have been if we had been in the most flourishing position. I could spend the whole of the five minutes allotted to me in dealing with Mr. Watts' speech, but I must turn to the highly important point that was raised by Mr. Campbell Swinton, because I think it is a point on which we ought to get some finality. It is a very important thing for us, who are so interested in the industry, to know whether companies which are subject to purchase in 1931, as they are in the Metropolis, should erect, out of their profits, a depreciation fund. I have always felt that they should set aside a depreciation fund which roughly represented the aging of the plant. Now Mr. Campbell Swinton raises a most important point, that possibly if they were to set aside such a depreciation fund the local authority might

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Mr. Hammond

claim the possession of that fund in 1931. If there were any fear of that, it is, of course, obvious that the companies would be most foolish if they did anything of the kind. It is difficult to say what is going to take place in 1931—I trust that Mr. Swinton and I may both be there to see—but if so, I expect we shall be engaged on opposite sides of the table in the arbitration, and then we will give them our views. In the meantime let us turn to the Act of 1888. The words in section 2 are distinct, that the local authority has the power of purchase upon the basis of the then value of the plant, machinery, and apparatus, consideration being had to the fact that it is in a position to give the supply, that is to say, it is to be bought as a going concern. I cannot conceive why any one should suppose that, after an arbitration as to the then value of the plant, the arbitrator should say, "But I hear you have £100,000 in the bank; will you please hand that over as well?" That seems to me to be straining an Act of Parliament in a manner in which I think Mr. Campbell Swinton would hardly do if he were called upon for advice by one of his companies. Surely a company is right in carrying out its business in the proper manner, and in providing for the depreciation which its plant is undergoing from year to year. I think that the London companies should work upon that basis, feeling absolutely positive that, when the time comes for an arbitration as to the then value of their plant, there will not be such a confiscatory arbitrator as to say that, "After having valued your plant at such and such a figure, you must now empty your pockets, and leave behind all the money you have in the bank—we will take it all." I do not share Mr. Campbell Swinton's fears on that point. The only other thing I desire to say is this: I thank Alderman Ewing Matheson for his very good exposition of the theory of depreciation, and as far as a company's undertaking is concerned, he certainly pointed out the proper method. So much money is set aside annually as a provision for depreciation; it is placed in the funds; money is spent in upkeep or renewals, and the fund is gradually decreased by the amount spent. But we must look at the matter also from the local authority point of view, where the money is being set aside in a sinking fund, and where we have not got the money except in that form. That sinking fund is earmarked for paying of the loan, and the money cannot be touched. With regard to the annual sum to be set aside, I would ask Alderman Matheson not to suppose I was postulating a case where the £100,000 was lent at no interest. He said I had only provided a sum of £2,742 16s. per annum, and he worked out that we could not squeeze 3 per cent. out of that as well as the sinking fund. I entirely agree. I assumed that any money borrowed was borrowed at interest, and that the interest charged was one of the working expenses. In alluding to the £2,742 I was referring to that sum of money which would have to be set aside annually and invested at 3 per cent. to wipe off the £100,000.

I thank you very much for the kind reception you have given to my paper; I only regret that the exigencies of time at the disposal of the

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Institution will not permit of it being adjourned for further consideration at another meeting, when I might be able to make a longer speech upon the points raised in the discussion. But that being impossible, I must content myself with thanking you, and hoping that the paper will sink into the minds of those who do not consider that it is necessary to put aside any depreciation at all in the case of electricity supply undertakings. Mr. Hammond.

(*Communicated*): The most important point raised in the discussion in Dublin is that by Mr. Brew, who disagrees with the main premise of my paper that the contribution of the local authority to the sinking fund for the repayment of capital should be treated as a contribution towards depreciation of plant. Mr. Brew seeks to put upon a local authority the obligation not only to erect a sinking fund by the operation of which the whole cost of the plant would be wiped off at the end of a given number of years, but also to accumulate a second fund at the rate of 4 per cent. per annum in order that by the time the original loan was paid off there would be a sufficient sum in hand to erect new plant. I do not consider that the present generation owes such a debt to posterity as to bear the burden of erecting this second fund.

The PRESIDENT: I will now put the resolution that we accord Mr. Hammond a formal vote of thanks in the usual way. The President.

The resolution was put, and carried with acclamation.

The meeting adjourned at 9.40 p.m.

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Proceedings of the Four Hundred and Fifty-Eighth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 2, 1907, Mr. W. H. PATCHELL (Vice-President) in the chair.

The minutes of the Ordinary General Meeting held on April 25th, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members:—

Stephen Newcome Wilson.

From the class of Associates to that of Associate Members:—

Alfred Anthony Blythen.
Charles W. Durnford.
William Kirkham.
John Kirkwood.
Charles S. May.
K. C. H. Newman.
Tyson Sewell.
William F. Whittaker.

From the class of Students to that of Associate Members:—

George B. Dyke.

Messrs. W. W. Buckton and A. E. Jackson were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

As Associate Members.

Peter Albertine.
John Ernest Rendell Baker.
Charles Percy Bramley.
John Filmer Davie.
Geoffrey Fairfield.
Joseph John Fasola.
Herbert John Hawkins.
Reginald William Hayman.
James Fox Heath.
Spencer Jewkes.

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As Associate Members (contd.).

Maximilian Kotyra.	Charles William Durie Newman.
Charles Lamb.	William Tuke Robson.
John Martin.	Cyril Ernest Taylor.
Wilfred John Maybery.	Ernest Rudland Wood.
Edwin Joseph Murphy.	Gladstone Walter Worrall, M.Sc.

As Associates.

James Herbert Brown.	Frank Gladwell Bussell.

As Students.

George Irvine Mercer.	James Herbert Sharp.
William Edwin Reid.	Newton Shuttleworth.
William Scott.	Edmund Sutcliffe.

Donations to the *Library* were announced as having been received since the last meeting from Captain E. W. Creak, R.N., F.R.S., the Engineering Standards Committee, Sir Oliver Lodge, F.R.S., the Physikalisch-Technische Reichsanstalt, C. J. Russell, C. F. Smith, and to the Benevolent Fund from L. Birks, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN: My first duty is to apologise on behalf of the President for not being able to be with us to-night.

Mr. Wade undertook some time ago, in connection with his firm, a large number of tests on the strength of poles for telegraph or transmission wires; and instead of publishing the results in the way that some firms would, in a little leaflet, he has been good enough to give them to us as a paper to the Institution. He has been helped in the matter by Professor Goodman, who made the tests on his behalf.

The following paper was read and discussed :—

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THE USE OF WOODEN POLES FOR OVERHEAD POWER TRANSMISSION.

By C. WADE (Hull).

(Paper read May 2, 1907.)

The employment of overhead high tension, and extra high-tension transmission of electricity has only come into vogue in this country within the last two or three years. Before that time the Board of Trade and local authorities were very strongly opposed to its use, and with the exception of a few short lines—mainly run on private property—there was little or no overhead high-pressure power transmission in Great Britain. For overhead structural work there was an old Board of Trade Regulation in force that "The factor of safety for wires should be 6, and for all other parts of the structures at least 12, taking the maximum possible wind pressure at 50 lbs. per square foot." This has now been reduced from 12 to 10 for the factor of safety on the structure, and from 50 lbs. to 30 lbs. for the wind pressure.

So strong was the feeling against overhead wires that the earlier Power Companies did not even seek to obtain powers for their use. In consequence, some hundreds of thousands of pounds have been sunk in the earth which might have been spent with far better results, both financially and from an engineering standpoint, on more comprehensive systems of overhead distribution. On the Continent and in America, nevertheless, the feasibility and economy of such systems have long been recognised and taken advantage of, and there are now many thousands of miles of overhead mains at work there carrying pressures up to 80,000 volts.

It is an easy matter to make electricity cheaply wholesale, but it is only by the use of overhead mains that it can be cheaply retailed over large areas. And there is no doubt that the distribution of cheaper power will help more than anything else towards the decentralisation of industries and the bringing of workers back to the land out of the present crowded and unhealthy centres of production.

The Power Companies have necessarily been the missionaries of overhead transmission in this country. They soon found that, in many cases, the cost of underground mains made it unremunerative for them to connect on customers whom they needed and who needed them. The Lancashire Electric Power Company was the first in England to bring the point to an issue. They approached the Board of Trade and

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were met by the authorities in a most friendly spirit. Plans were submitted and approved, way-leaves were arranged, and to-day the Company has about 4½ miles of overhead mains safely, economically, and reliably transmitting power at 10,000 volts pressure to a variety of industries. The lead of the Lancashire Power Company was quickly followed by the South Wales, the North Wales, the Clyde Valley, the Cleveland and Durham, and other companies, and there are now some 55 miles of extra high-tension overhead transmission lines at work in Great Britain.

To those who have studied the subject—especially abroad—it seems strange that this country can only boast, in 1907, of having 55 miles of overhead mains at work. In the districts round Grenoble, Lyons, and at St. Etienne, to give only one example, there are some 700 miles of overhead power mains at work carrying energy at pressures varying from 200 to 26,500 volts. These mains are for the most part carried on ordinary telegraph poles along the sides of the main roads, and are looked on by the inhabitants as part of their daily surroundings and as necessary to their prosperity as the high roads and railways of the districts.

One overhead line near St. Etienne, 11 miles in length, carrying energy at 5,500 volts pressure, was erected for £160 per mile, and this sum included wayleaves, special precautions when crossing roads and railways, and the purchase of trees that were in the way of the line. It is interesting to note that some 4,000 silk looms are connected to these mains, divided amongst hundreds of peasant proprietors who own from two to ten looms each. This is a very striking example of the benefits of cheap electrical power rendered possible by the employment of overhead distribution.

It is probable that overhead power transmission would never have been allowed in this country had it not been for the rapid extension of the electric tramways, which first accustomed the public to transmission by overhead wires.

The ordinary 550-volt trolley wire, however, of which there are many thousands of miles, has not only to carry its own weight and its current, but it is continually subject to severe mechanical stresses. It is far more dangerous than any power-transmission line at whatever pressure.

The first extra high-tension overhead line in this country was put up —more or less—by rule of thumb. There were no reliable data from which to settle the requisite strength and size of poles employed. The subject was one of the greatest importance, as it was essential, on the one hand, that the capital cost of the construction and erection should be kept as low as possible; and, on the other hand, that overhead transmission should not be discredited by failure, accident, or disaster. The author, therefore, in August and November, 1906, in consequence of a communication from Mr. A. P. Trotter, of the Board of Trade, carried out an exhaustive series of tests on wooden poles of varying form, lengths, and diameter. During these tests the author had the advantage

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of the advice and help of Professor Goodman, of Leeds, and the tables printed with the paper were prepared by him.*

The first set of tests was carried out in August, 1906, and both single and double poles were experimented upon. The results, however, were not considered satisfactory, as the arrangements for testing were found to be far from perfect. The method adopted of loading and holding the poles caused a large amount of friction which prevented the obtaining of accurate results.

These tests clearly proved: First, the very marked superiority of an "A" over a single pole, the "A" pole being shown to be at least three times as strong as a single pole, while later and more accurate tests have shown that the "A" is at least four and a half times as strong as a single pole; second, the great flexibility and recuperative power of wooden poles (Fig. 1). Some single poles that were tested projected free for 35 ft. from their housing and deflected 13, 14, and 15 ft. before breaking; and those that were released before the breaking-point was reached showed a very small permanent set. It was soon seen that "A" poles were preferable to single poles both as regards economy and strength. To obtain the required strength *in single poles*, they would have to be of such a diameter as to be prohibitive in cost, and in some cases unobtainable. Most attention was therefore bestowed on testing the strength of "A" poles and on their construction.

Fig. 2 shows the first method of testing the poles that was used in August. It being desired to hold the butt of the pole firmly to a height of 5 ft., whilst the rest of it was allowed to swing free, two heavy timbers, B and C, were driven into the ground, B for holding the foot of the pole and C for taking the stress 5 ft. up. The top end of the pole was supported on a specially constructed trolley, which ran on a platform under this end of the pole. It was first attempted to load the pole by weights placed on a wooden platform, suspended from the end of a wire rope attached to the pole, and carried by a series of pulleys to the top of a substantial frame about 12 ft. high. The platform when heavily loaded sank into a pit dug below the frame (Fig. 3).

This method was abandoned on account of the friction of the pulleys and the time occupied in loading. In subsequent tests the load was obtained by a gang of men with pulley-blocks at F, and a dynamometer (Fig. 4) was inserted in the loading chains near this point.

A similar method of holding was adopted in testing "A" poles on the flat—*i.e.*, along the line of the wires—and was satisfactory. This acted admirably for single poles, but when "A" poles were tested across the line of the wires in precisely the same manner it was found that, owing to their taper construction, there was so much end slip in the housing, as shown by the arrows, that accurate results were impossible (Fig. 5). When it was found that the strength of "A" poles was the really important point to determine, the author, acting on Professor Goodman's suggestions, redesigned and reconstructed the

* In his reply to the discussion the author states that the poles tested were red fir.

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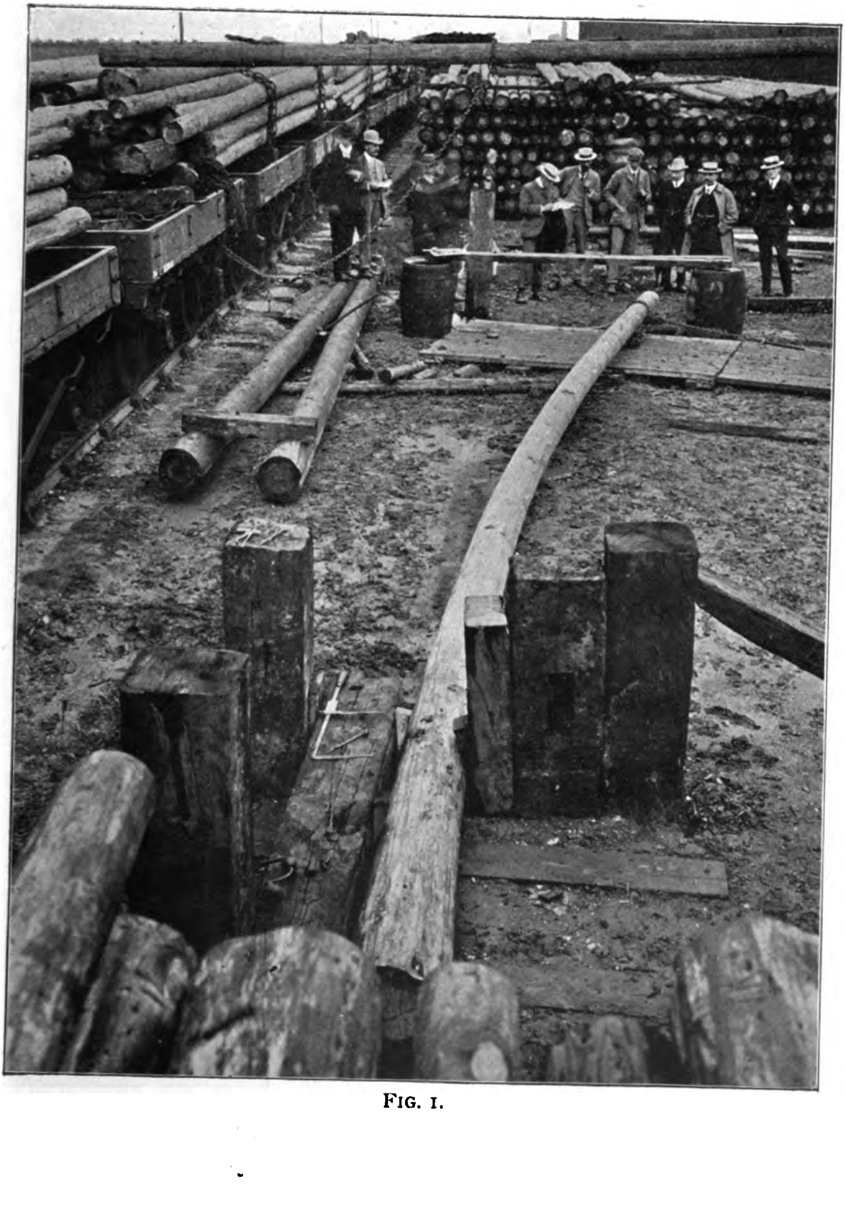

FIG. I.

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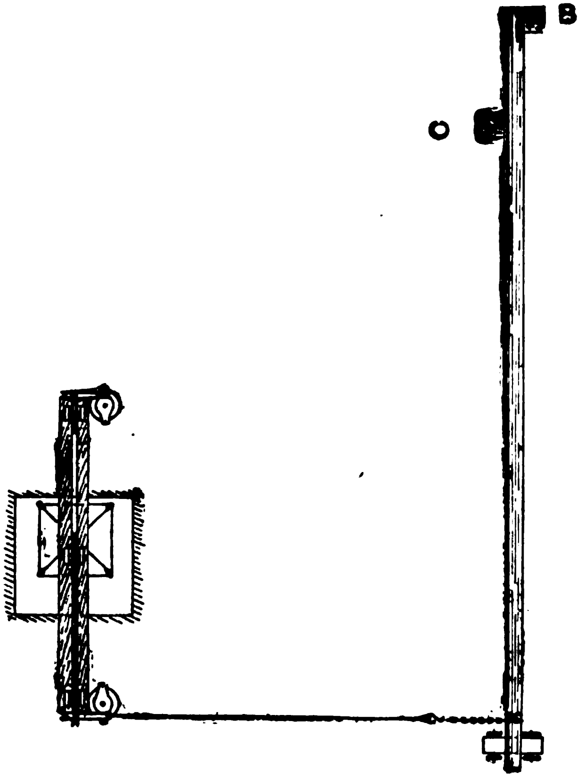

FIG. 2.

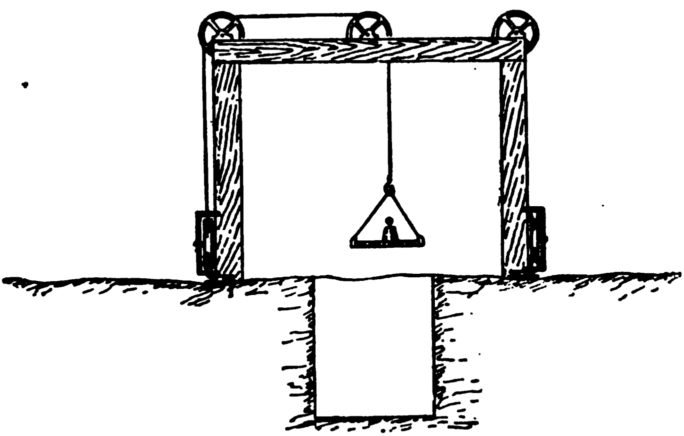

FIG. 3.

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testing apparatus and the methods of housing the poles, and carried out a new series of tests in December.

In this series of tests—confined almost entirely to "A" poles—a different method of holding was adopted to prevent the poles from slipping in their housing, as shown in Fig. 6. All the poles were about $7\frac{1}{2}$ to 8 ins. diameter at 5 ft. from the butt. The double pole being

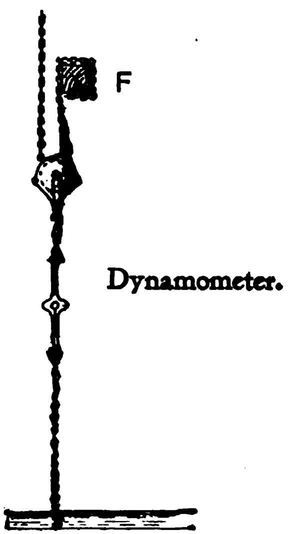

FIG. 4.

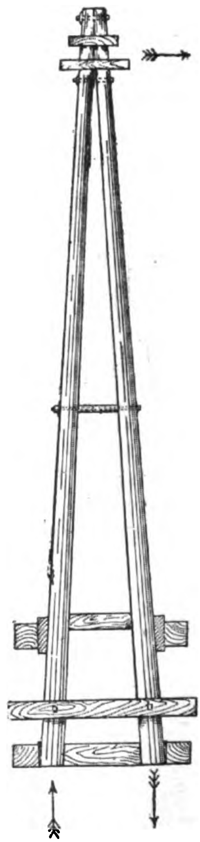

FIG. 5.

placed in position, as shown, two heavy blocks E F were bolted to it, one below and one above the pair of poles, about 2 ft. 6 ins. from the butt, and, in addition, a heavy iron ring G was bolted to the tension leg of the pole, below the blocks, to prevent them slipping down when under load. The foot of the pole was embedded against a massive timber R S, supported on the poles B D. A block H was inserted, as shown, to give additional stability.

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By this means when the load was applied in the direction of the pile W, the leg that was under *tension* was unable to move away from the balk A and its supports on account of the oak cross timbers, whilst the leg that was in *compression* was also unable to move as its foot was

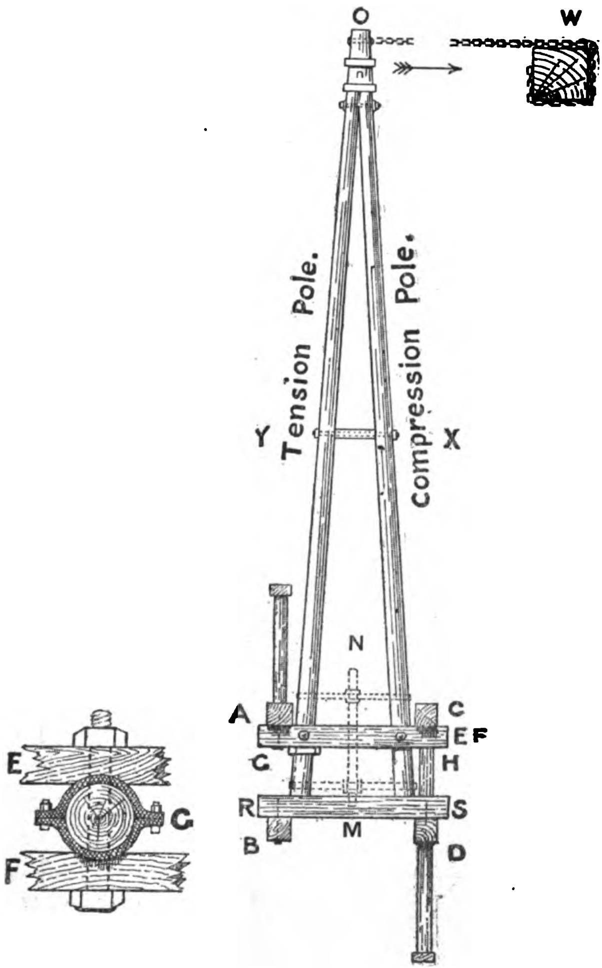

FIG. 6.

pressing against the timber R S. The pole was therefore very rigidly held in place, in fact, far more so than would occur in actual practice.

Professor Goodman suggested and provided a telescope, which was attached to the butt of the pole at M N (Fig. 6), and by this means it was possible to sight a plumb-bob, suspended at O, so that accurate

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readings could be obtained and any slip of the pole in its housing could be detected and allowed for. The use of a telescope in tests of this kind is a very necessary refinement that is too often overlooked, and one was used by the author in all tests made. The housing required to be of great strength. The author believes that the results of these tests given in the tables are accurate, as very great care was taken to make them so. In all probability if a load equal to the test-load were applied to a pole carrying wires the whole structure would be pulled out of the ground.

The load was applied in the same manner as in the first series of tests—by pulley blocks—and everything possible was done to eliminate friction. The weight of the pole was taken at the top end by a chain hung from a large pulley running on an overhead cross-pole supported on tripods at each end. This pulley was guided by a line on each side, and the cross-pole was fixed as nearly as possible level and in the line of the pole's deflection.

In these tests it was found that whereas a single pole would often deflect to a very large extent before breaking, an "A" pole, so long as it held together at the top, would only deflect a few inches. The "A" pole, however, would sustain in a direction across its two members—*i.e.*, at right angles to the line—a load four or five times as great as that of a single pole of the same diameter as one of the two members of the "A" pole. Also experiments show that an "A" pole (as would be expected) is at least twice as strong as a single one of equal section, in the direction of the line, and would only deflect half as much.

Figs. 7 and 8 show that the "A" poles failed in nearly every instance through the buckling downwards of the member in compression. This was due to the initial sag of this member, caused by its own weight, which it was impossible to allow for. To have eliminated this sag it would have been necessary to support the poles in the centre which would have caused friction, and this it was particularly desired to avoid on account of such friction affecting the accuracy of the results. This was thought of and discussed at the time, but it was decided to carry out the tests in the manner shown. This sag undoubtedly made the poles fail sooner than they would have done had they been in a vertical position, and the results, therefore, are less favourable than they would be in actual practice. But it should be noted that at this point of failure the poles were not actually broken in any way, and if it had not been for the sag out of the line of pull they would undoubtedly have sustained far greater loads. The buckled pole in all cases straightened itself immediately the load was released. In every case the load was applied approximately 2 ft. from the top of the pole, this being about the point where the stress would occur in actual work.

In 1885 Mr., now Sir William, Preece, Chief Engineer to the Post Office, carried out a series of tests as to the strength of single poles. Many different kinds of poles were tested that had been seasoned for different lengths of time, and tests were made on creosoted and plain poles, of different lengths and diameters. These tests, however, did

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FIG. 7.

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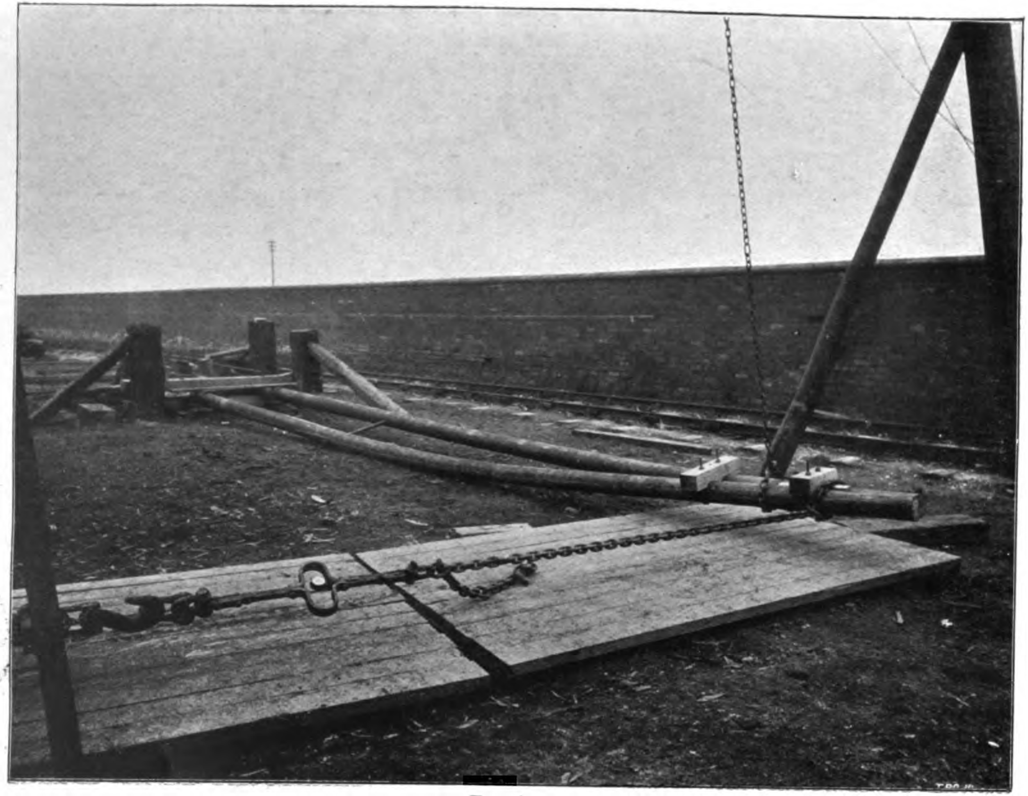

FIG. 8.

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not deal with the flexibility of the poles, nor with their strength, as compared with composite poles, but they are still the only data that we have on the strength of ordinary poles.

From the tests carried out by the author, it appears that many of the poles in use in this country are misproportioned, and this applies particularly to "A" poles. Some are ridiculously too large, while others are dangerously too small. The few that are correct in length and size have been selected more by luck than judgment. The tests showed that the usual breaking-point of a single pole, when tested to destruction, is about 5 ft. above ground level, or about 10 ft. from the butt. The diameter of a pole at this point is, therefore, the most important dimension to consider in choosing one suitable for certain loads. The top diameter of a pole is also of some little importance, but this is a dimension which Nature settles, and there is no object in altering the natural taper, although the author remembers one instance when an inspector visited his works to pass certain poles, and the specified diameter at the top and butt, having been measured with red tape, disagreed with Nature's. The poles were found to be about 1½ in. too large in diameter at the top, and they had to be reduced before being accepted.

The weakest point of an "A" pole is the top, where the stress due to windage and weight takes place. The two members of the pole—owing to their shape—have a tendency to slide and slip on each other when subjected to a load at the top. One member being in compression and the other under tension, that which is under tension elongates and forces itself away from the member in compression.

The important thing about an "A" pole is its construction and the method adopted to hold its two members at the top. The author's method of securing them is shown in Fig. 9. The two members are scarfed to such an extent as to reduce them to about two-thirds of their original diameter. The length of the scarf depends, of course, on the angle at which the members are set. They are held together by two ¾-in. bolts, one about 12 ins. and the other about 48 ins. from the top of the poles. At the foot the two members are tied together by a wooden block about 6 ft. in length, and 4 ins. × 8 ins. in section, which is let into and bolted to each about 2 ft. from the butt. It will be noticed that the arrangement is similar to that adopted in the tests, which were designed to follow, as closely as possible, the conditions occurring in actual practice.

A centre tie bolt and tubular distance piece is also used between the two members about 10 ft. above the ground level. Instead of this tie bolt, flat iron plates, fixed diagonally across the poles and bolted to the pole at each end, can also be used with advantage (Fig. 10), by which means, undoubtedly, the pole is materially strengthened, and is prevented from twisting. Angles or channels bolted to each side of the pole, across the two members, serve the same purpose. It is also desirable to insert an oak block in the scarf. This block should be 6 ins. deep and should be let into each member to a depth of about 1 in.,

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depending on the size of the pole used (Fig. 11). The tests showed that if the blocks are less in depth or if they are nearly square they tend to twist and bed their corners into the poles and thus force the members apart. One deep block in the scarf appears to be better than several of less depth, inasmuch as the insertion of several blocks weakens the timber, and if they are fixed high up they will—when

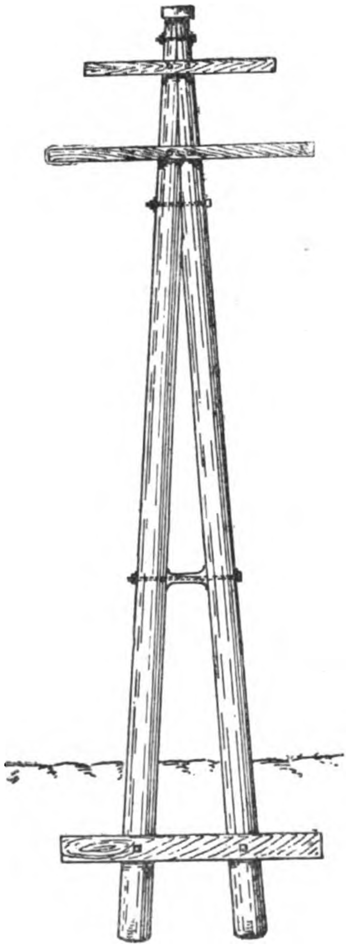

FIG. 9.

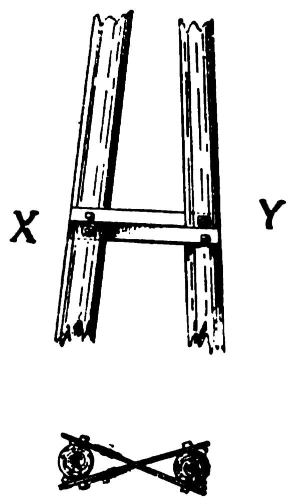

FIG. 10.

under stress—squeeze the top part of the member on which they bear clean out of the end of the pole. The oak arms let into the poles to carry the insulators materially strengthen the structure and prevent shearing. For the construction of "A" poles the author recommends this method, which is the one usually adopted, but other methods are sometimes employed.

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The lower insulator arms are sometimes tied to the centre of the pole by flat ties or iron plates, which helps to prevent the twisting of the arms and the parting of the two members. The tying together of the ends of the lower and upper arms also helps to strengthen the structure. It is, of course, most important that as little cutting away as possible be done to the poles, especially at the top, as this weakens the timber.

Whether insulator arms should be composed of oak or angle or

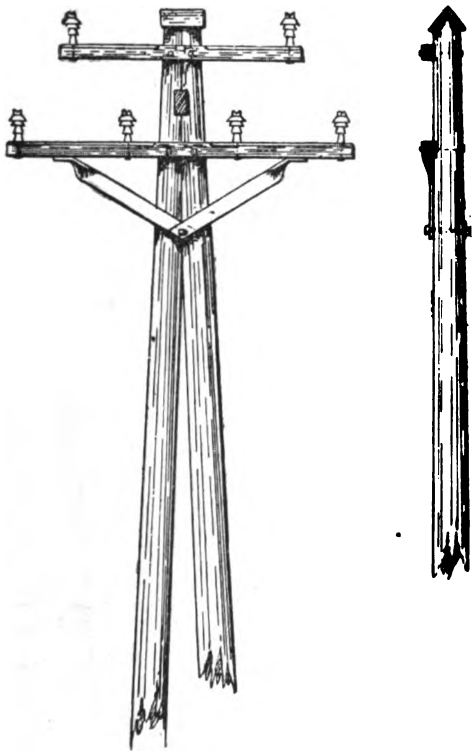

FIG. 11.

channel iron seems a very open question, into which the question of insulation and earthing enters very largely. The life and strength of a wooden arm seem to be equal to those of an iron one, if not more, and wooden arms will no doubt outlast the pole, and are slightly cheaper than iron. The author has carried out experiments with different forms of castings designed to hold the two members together at the top, both when scarfed and unscarfed. The poles were placed together side by side and held together at the top by the castings.

First (Fig. 12) experiments were made with a casting which

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enveloped the two members of the "A" pole, after scarfing, between the two usual oak arms. This casting was made in two separate halves, held together by three strong bolts passing through them and between the two members of the "A" pole. The casting was so designed that when drawn up tight on the pole the two halves of it did not quite meet, and at each end of it flanges were formed for the attachment of the two oak arms, these arms being let into the pole to assist in preventing twisting of the members of the pole. The arrangement seemed to hold very well, and only failed in the end through the splitting of the casting as shown in Fig. 13, probably owing to a fault in it, or through having

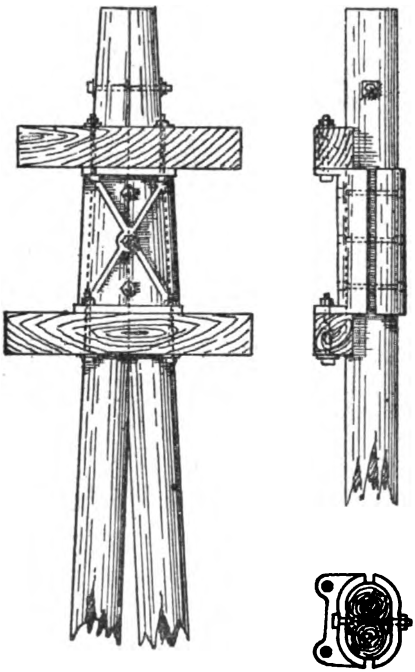

FIG. 12.

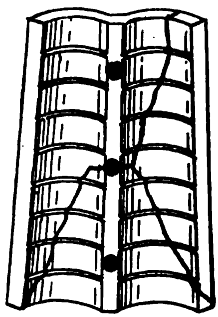

FIG. 13.

been tightened up too much in fitting it to the poles, which thus sustained a comparatively small load, but gave a comparatively small deflection on account of the rigid manner of tying at the top.

The second casting was formed to envelope the two members of an "A" pole when tied together at the usual angle (Fig. 14) without being scarfed or bored in any way at the top, and it was made in two pieces as in the previous case, but was bolted together at the edges as well as in the centre. This failed in the first instance through the slipping of one member of the pole in the casting, whilst the other held fast, the failure being due to the inequality in size of the two members

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in consequence of which the casting did not obtain an equal grip on both members. This was afterwards remedied by the careful selection of two members of equal size, when the result was more satisfactory, and the pole, with one exception, sustained a higher load than any other and gave a comparatively small deflection, failing in the end through the buckling of the compression member. The slip of the two members on each other at the top was practically nil. In the author's opinion this is the best means of tying the two members together at the top, and would seem to justify the extra cost involved by the more satisfactory results obtained.

A means of holding the two poles together was also tried (Fig. 15A)

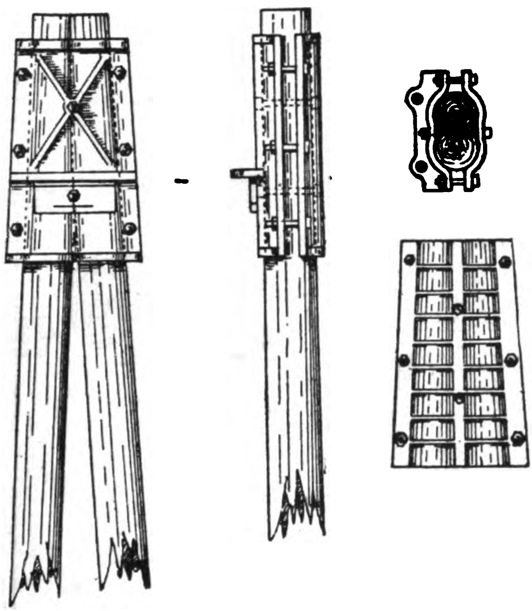

Fig. 14.

in which the two members were scarfed together in the usual way and the arms were secured to the poles by wrought-iron bands, the ends of which passed through the arms. A centre bolt was also passed through the backing plate to the other side of the clamp as an additional means of tightening up. An oak wedge was driven up between the two poles to give rigidity, and was held in place by these bolts, and as an additional precaution both members were bolted together by a through tie bolt passing through them at the top and also through an oak block inserted in the scarf at this point. The result obtained was distinctly good, the load being high before failure, although the deflection was fairly large.

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This method of holding was considerably improved (Fig. 15B) by placing the oak arms below the plates and letting them into the poles, as shown, which gave them an additional means of preventing twisting. The result obtained showed a great improvement, the load being higher and the deflection distinctly less.

A method was also tried in which a solid casting was placed over the two members after being scarfed (Fig. 16); and having been closely fitted, was secured by a bolt passing through the two poles at its base. This gave good results, but the casting shifted considerably out

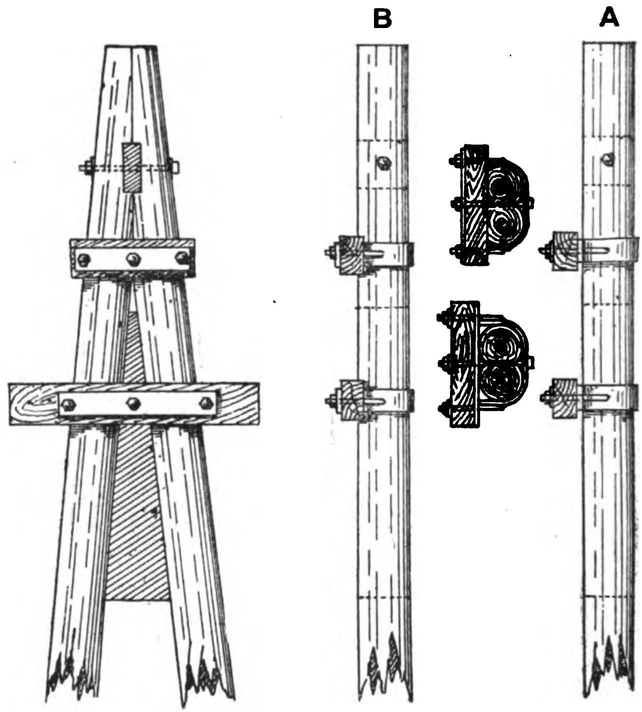

FIG. 15.

of the perpendicular under load. The casting originally was formed with a flange to carry the oak arm some way up. Though the load sustained was good, it was not enough, in the author's opinion, to justify the necessary expenditure.

This shifting was avoided to a great extent by the insertion of an oak block in the scarf, and an oak arm let into the pole lower down also assisted in preventing twisting. When tried again the pole gave better results, but not so good as was expected. It failed in the end through the fracture of the tension member as shown.

It would, no doubt, be better to place the flange lower down, at the

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bottom of the casting, and to let into the pole the arm carried by it. This is a cheap arrangement, and in addition it has the advantage of excluding all wet from the top of the pole and also of forming a cap for it, which can be drilled to receive the insulator pin of one line when it is desired to place the line at the top of the pole.

In this series of tests carried out by the author and Professor Goodman on the 12th and 19th of February, a heavy "A" pole, each leg being about 11 ins. diameter at 5 ft. from the butt, which had been previously tested in August, was tested again, in order to determine the comparative merits of the two methods of holding it in the housing, it was found that the loads sustained were considerably higher than before, and the failure in the end was caused by the twisting of the oak blocks in the scarf. These, which had been made nearly square, were replaced by longer ones.

Fig. 17 shows the effect of the enormous stress on these blocks. The pole was then tested again and the load it carried was the highest obtained—about 4 tons, the deflection being only about 14 ins.—not very great considering the weight on it. The final failure was caused, partly by the twisting and splitting up of the blocks in the scarf, but principally by the twisting of the oak cross-pieces, which took the load at the foot. These gave way under the enormous pressure they had to bear, and further results were unobtainable although the two members were perfectly sound at the finish, and not in any way cracked or bent to any visible extent.

Tests were also made with "A" poles spread to different widths at the bottom. The spread which gives strength combined with cheapness of erection was found to be about 4 ft. on a 32-ft. pole, or a taper of about 1 in 8, the measurement being made between the centres of the bolts holding the brace, which tied the members together near their butts. If a smaller spread than 4 ft. is adopted the poles are not so strong, while a greater spread, though giving some extra strength, increases the cost of excavation and wayleaves.

All figures given in the tables were taken from tests of "A" poles with a 4-ft. spread, measured as above, except where otherwise stated.

A favourite form of constructing a double pole is the "H" formation, Fig. 18, wherein the two members are erected parallel to each other, and are held together by the arms at the top, being strengthened lower down by cross-bracing, or by tie bolts. Their strength depends, of course, entirely on the method and amount of bracing, and if this is extensively done, they will no doubt be as strong, if not stronger, than "A" poles of equal size. They have the advantage of presenting a greater surface than an "A" pole to which to attach wires, and are especially useful for terminals of lines for this reason. When used as terminal poles they are stayed with two or four steel rods or wire ropes at the back, to take the stress of the line.

This "H" formation is also extensively used by the leading users of telegraph lines and telephones for main routes, where the poles have to

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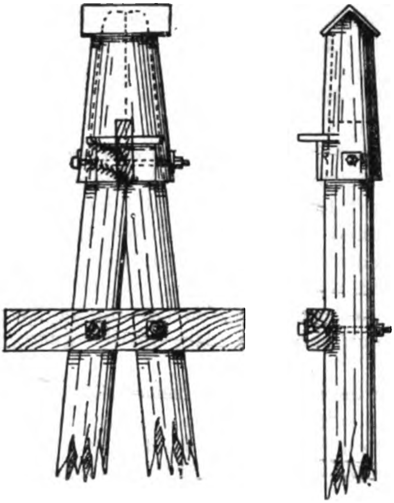

FIG. 16.

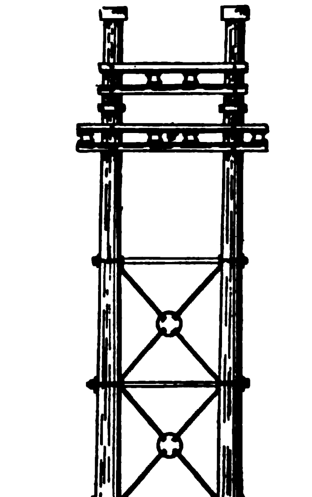

FIG. 18.

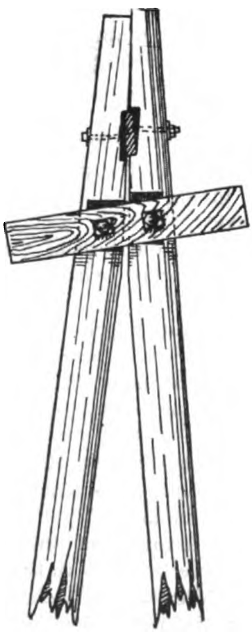

FIG. 17.

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carry a large number of wires, and where a single or "A" pole would not give the requisite surface.

One advantage of wooden poles that the tests have conclusively proved, is their great flexibility and recuperative power after severe deflections from the perpendicular, caused by abnormal stresses. Such stresses are frequently caused during frosts by the contraction of the wires. Where wooden poles are employed, in the very unlikely event of the breaking of all the wires on one side of a pole (Figs. 19 and 20), the first pole on each side of the break would deflect, and each pole further on in either direction would deflect proportionately, thereby preventing any poles breaking and reducing the probable cost of repairs to a minimum. As soon as the line was repaired the poles would come back to their original positions. For further information upon the behaviour of poles under such conditions, reference may be made to Mr. Trotter's paper on overhead transmission, recently read before the Institution of Civil Engineers.

Iron poles, steel lattice masts, and reinforced concrete poles have been used for this class of work, but the author considers that in the event of a breakage, as mentioned above, they would not have sufficient flexibility to enable them to recover. Moreover, they would cost more to buy and erect, and would be much heavier and need better foundations than wooden ones. Again iron or steel poles would need to be repainted at least once in three years, and, however much care was taken to preserve them, their corrosion would be so great that frequent renewals would be required, whereas a wooden pole, which had undergone an effective preserving process, have been known to last for fifty years without attention. Creosoting has been generally adopted by the General Post Office, The National Telephone Company, the leading Railway Companies, and all large users, and gives general satisfaction.

It is most important in creosoted poles not to cut the treated surface if it can be avoided. Cutting away renders useless the most valuable part of the process, as the oil penetrates chiefly the outside or soft part—which is sapwood—of the timber, and any part which it is found necessary to cut after creosoting should be thoroughly tarred over.

It has often been asserted that wooden poles are unsuitable for certain climates such as prevail in East and West Africa, in parts of India, and elsewhere. The author believes that this is still an open question, and he has sent poles to those parts of the world to be tested, and hopes before long to be able to give some definite information on the subject.

He also hopes that the novelty of the tests he has carried out may prove of interest to the Members of the Institution. And, in conclusion, he wishes to thank Mr. Trotter, Professor Goodman, and others, for their help and advice. His labour will have been amply rewarded if he has been able to place before the Institution and the great profession represented by it, a few reliable figures and data on a hitherto unknown subject.

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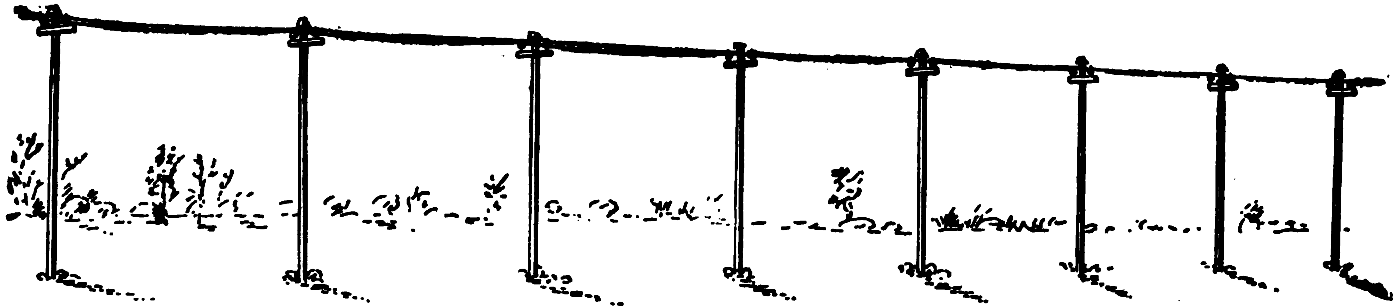

FIG. 19.

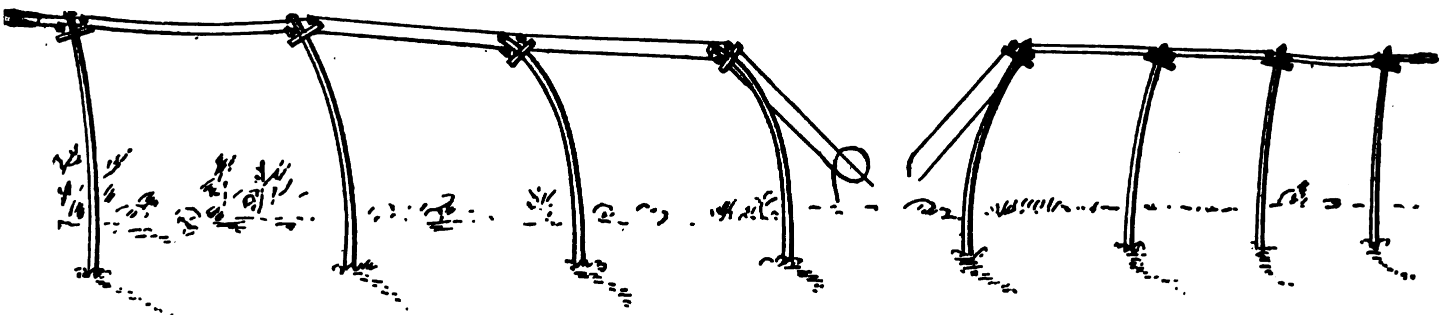

FIG. 20.

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APPENDIX.

BY

PROFESSOR GOODMAN, M.INST.C.E.

SINGLE POLES.

The results of isolated tests of poles are of little value unless data can be derived from them which can be utilised in calculating the probable behaviour of poles in general. In the following treatment the timber is assumed to be perfectly elastic for working stresses, and further, that the ordinary formulas for elastic beams hold for timber. It is well known that, although such assumptions are not altogether justifiable, they give correct relative results. The beam formula only professes to be true for elastic materials, therefore it should not be used for calculating the breaking strength of beams unless a suitable "Modulus of Rupture" be taken in the place of the ultimate strength of the material. The tests on single poles described in this paper supply this data; but since the number of single poles tested was too small to generalise from, the modulus of rupture obtained in former Post Office tests has therefore been adopted in calculating the tables of the breaking strength of single poles. A comparison between the results obtained by the Post Office and in the tests by Mr. Wade and myself is, however, of interest. In addition to the tests made in the timber yard further bending tests were made in the Buckton testing machine at the Leeds University.

The method of reducing the results is as follows :—

Let—

W = the breaking load in pounds applied at a point 2 ft. from the top of the pole.

R = the radius of the pole at the ground level, in inches.

R_m = the mean of the top and bottom radii of the pole, in inches.

R_1 = the radius of the pole at the ground level, in inches, in the plane of bending when not truly circular in section.

R_2 = ditto, normal to the plane of bending.

R_{A1} = the radius of one of the "A" poles at the ground level, in inches, in the plane of bending.

R_{A2} = ditto, normal to the plane of bending.

L = the length of the pole, in inches, measured from the ground level to the point of loading.

L_o = the overall length, in inches.

G = the length of the pole, in inches, embedded in the ground.

T = the distance in inches, from the top of the pole to the point of loading in the actual pole tested.

S = the "spread" or "splay" of an "A" pole at the bottom, in inches.

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f = the "modulus of rupture" for the pole in pounds per square inch.

K = the Post Office constant for comparing similar beams.

$= \frac{f}{6}$.

d = the elastic deflection, in inches, under a load of 1,000 lbs. applied at the extreme end of a unit pole 12 ins. long, 1 in. diameter, and of the same taper and material as the tested pole.

D = the elastic deflection, in inches, at the point of loading of the actual pole when tested.

D_e = the deflection, in inches, at the extreme end of the actual pole tested.

E = Young's modulus of elasticity for timber, in pounds per square inch.

I = the second moment or moment of inertia of a pole section in inch units.

$= \frac{\pi R^4}{4}$ for a circular pole.

$= \frac{\pi R_1^3 R_2}{4}$ for a pole whose section is not truly circular.

d_w = the diameter, in inches, of each wire or cable supported by the poles.

L_s = the length of span of the wires in feet, *i.e.*, the distance from pole to pole.

From the theory of bending, we have for a rectangular beam of breadth b and depth h—

$$\text{Bending moment at fracture} = f\frac{b h^2}{6}.$$

For a cantilever, such as a telegraph pole of rectangular section this becomes—

$$W L = f\frac{b h^2}{6}$$

$$\frac{W L}{b h_2} = \frac{f}{6} = K \quad \text{(the Post Office constant),}$$

$$\text{or } f = 6 K$$

In a beam of circular section we have—

$$W L = \frac{f \pi R_1^2 R_2}{4}$$

$$\frac{4 W L}{\pi R_1^2 R_2} = f = 6 K,$$

hence—

$$K = \frac{4 W L}{6 \pi R_1^2 R_2} = \frac{W L}{4{\cdot}7 R_1^2 R_2},$$

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or when the pole is truly circular in section we have—

$$K = \frac{W L}{4{\cdot}7 R^3},$$

The value of K is obtained from a breaking test of a pole, then the breaking load of any other similar pole is given by—

$W = \dfrac{4{\cdot}7 R_1^2 R_2 K}{L}$ for a pole which is not truly circular in section,

$W = \dfrac{4{\cdot}7 R^3 K}{L}$ for a pole of circular section.

For arriving at the deflection of poles we proceed thus :—

From the theory of bending we have, for a load W less than the elastic limit—

$$D = \frac{W L^3}{3 E I} = \frac{4 W L^3}{3 E \pi R^4}.$$

Putting $W = 1{,}000$ lbs. for the unit pole conditions—

$L = 12$ ins.,
$R = 0{\cdot}5$ ins.,

then the corresponding deflection of the unit pole is—

$$d = \frac{4 \times 1{,}000 \times 12^3}{3 E \pi \times 0{\cdot}5^4}$$

$d = \dfrac{27{,}648{,}000 R^4 D}{W L^3}$ for a pole of circular section,

or $d = \dfrac{27{,}648{,}000 R_1^3 R_2 D}{W L^3}$ $\Big\{$ for a pole whose section is not truly circular.

The value of d is found by experiment.

To calculate the deflection of any other pole of similar material and taper we have—

$D = \dfrac{W L^3 d}{27{,}648{,}000 R^4}$ for a pole of circular section,

or $D = \dfrac{W L^3 d}{27{,}648{,}000 R_1^3 R_2}$ for a pole not truly circular in section.

The deflection at the extreme end is greater than at the point of loading, and is obtained thus :—

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$$D_e = D\left(\frac{2L + 3T}{2L}\right).$$

A refinement might be introduced into these expressions to allow for the difference in the taper of various poles, but the expression is somewhat cumbersome and is quite unnecessary for practical purposes.

The manner in which the above-mentioned expressions are arrived

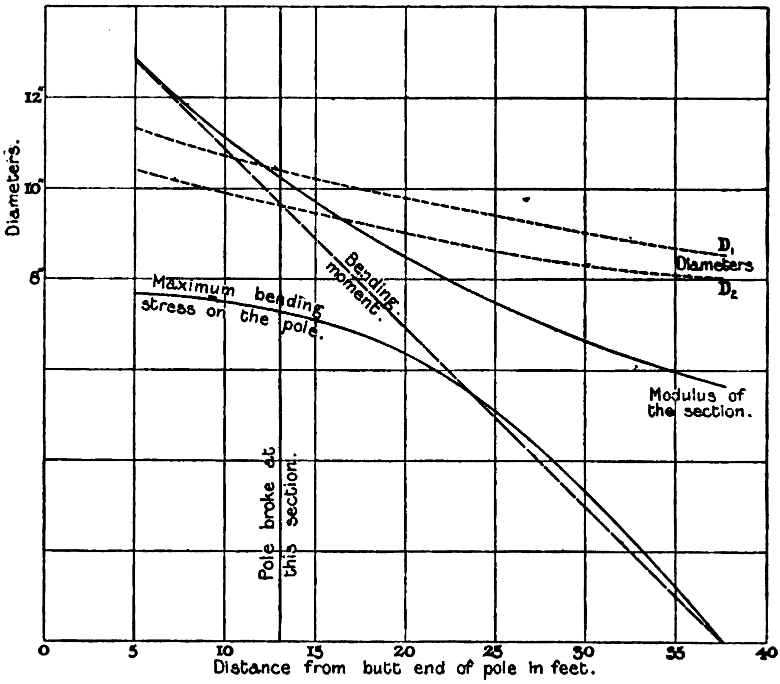

FIG. 21.

at is fully set forth in Goodman's "Mechanics Applied to Engineering," chaps. ix., x., xi.

In the experiments on the breaking strength of single poles it was found that they did not break where expected, namely, at the section close to the ground where the stress was greatest, but at a section 6 or 7 ft. above the ground. The actual bending stress at various heights above the ground is shown in the accompanying diagram (Fig. 21), from which it will be seen that the pole actually broke at a section where the stress was less than at the ground level. It was thought that this peculiarity might be due to the strength of the timber being greater at the butt than at sections higher up the pole, but the following bending

experiments made on different pieces of the same pole in the testing machine shows that this was not the case :—

TABLE I.

Diameter in Inches.	Modulus of Rupture in Tons per Square Inch.	Position of the Fracture.
7·5	3·15	About 8 ft. from butt.
7·2	2·94	" 14 " "
6·7	3·10	" 20 " "
6·2	3·09	" 26 " "
5·4	2·92	" 32 " "

WIND PRESSURE.

The chief lateral stresses to which telegraph and overhead transmission poles are subjected are due to wind pressure acting on the wires and on the poles themselves. The wind pressure assumed by the Board of Trade for high-voltage overhead transmission work is 30 lbs. per square foot, which in the opinion of many is far too high for inland work, but it may not be excessive for very exposed positions on the coast. The above-mentioned pressure is for the wind acting normally to a flat surface; in the case of a cylindrical surface, such as a wire or pole, the resistance to the wind is only 0·5 to 0·66 of that on a flat surface; for the wires we shall assume the higher value, namely, 0·66, and the lower value for the poles, mainly because it is well known that the pressure of the wind diminishes as we approach the ground.

The wind pressure on one wire is, on these assumptions—

$$\frac{30 \times 0{\cdot}66 \times d_w \times L_s}{12} = 1{\cdot}67\, d_w\, L_s.$$

The wind pressure on a pole is—

$$\frac{30 \times 0{\cdot}5 \times 2\,R_m (L_o - G)}{12 \times 12} = \frac{R_m (L_o - G)}{4{\cdot}8}.$$

The resultant of this pressure acts at a point approximately half-way up the pole, hence the equivalent pressure acting at a point 2 ft. from the top of the pole, *i.e.*, where the resultant pressure due to the wind on the wires is assumed to act, is—

$$\frac{R_m (L_o - G)}{4{\cdot}8} \times \frac{(L_o - G)}{2\,L} = \frac{R_m (L_o - G)^2}{9{\cdot}6\,L}.$$

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Hence the net safe load for a pole, *i.e.*, the safe load it will support in the shape of wind pressure on the wires, is, for a factor of safety of 10—

$$\frac{4{\cdot}7\, R_1^2 R_2 K}{10\,(L_o - G - T)} - \frac{R_m (L_o - G)^2}{9{\cdot}6\,(L_o - G - T)} \left\{ \begin{array}{l} \text{for a pole not truly} \\ \text{circular in section;} \end{array} \right.$$

or—

$$\frac{4{\cdot}7\, R^3 K}{10\,(L_o - G - T)} - \frac{R_m (L_o - G)^2}{9{\cdot}6\,(L_o - G - T)} \left\{ \begin{array}{l} \text{for a pole of} \\ \text{circular section.} \end{array} \right.$$

"A" Poles.

The theoretical treatment of single poles is a tolerably simple matter, and can be relied upon within narrow limits, but we cannot say the same with regard to "A" poles, as there are so many uncertain factors. If we could be quite certain of the joint at the apex of the poles and knew exactly the conditions as regards the end holding, we could probably obtain from first principles quite reliable expressions for the strength and behaviour of such poles; but since both of these are very uncertain quantities, we are obliged to resort to experiments. The tests made by myself and Mr. Wade fortunately give data which are believed to be quite reliable, and it only remains to reduce the results to such a form that the probable behaviour of all similar structures can be calculated.

It will be seen that when an "A" structure is loaded, as in Fig. 6, the one leg is subjected to tension and the other to compression, the force in each being $\frac{WL}{S}$; the structure may therefore fail by tearing apart the tension pole, by buckling the compression pole, or by shearing the apex joint. With the exception of one faulty pole, none of the "A" poles tested failed in tension, therefore we need not further consider the strength from this point of view. Several, however, failed by shearing at the top joint (see results quoted later). This source of weakness was, however, overcome by adopting an improved joint, which was the outcome of these tests, and details of which are given in the body of Mr. Wade's paper. Most of the poles failed when under test through the buckling of the compression pole (see photographs Figs. 7 and 8).

If the pole were pivoted at both ends, or were otherwise arranged so that it would be free to bend in any direction, the buckling load could be readily calculated, similarly if it were held rigidly at one or both ends; but, as a matter of fact, it is neither a simple case of rigid holding nor pivoting, hence we must find by experiment what is approximately the system of end holding. If the pole were pivoted its equivalent length would be equal to its actual length (see "Mechanics Applied to Engineering," chap. xiii.), and if it were rigidly held at both ends its equivalent length would be one-half its actual length. The tests appear to show that owing to the central stay and the scarfing

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of the joint this is about the equivalent length of the compression member of an "A" pole. The buckling load of a timber pole held at both ends is, by Gordon's formula, with constants for soft timber—

$$\text{Buckling load in pounds} = \frac{21{,}000{,}000\ R^2}{2{,}000 + \left(\frac{L}{R}\right)^2} = \frac{W\,L}{S}.$$

Hence the load on the apex of the "A" pole in pounds, at which the compression leg will fail by buckling, is—

$$W = \frac{21{,}000{,}000\ S\,R^2}{\left\{2{,}000 + \left(\frac{L}{R}\right)^2\right\} L}.$$

A table will be given shortly showing how values calculated by this formula agree with the experimental values.

For practical purposes it is convenient to use the same expression for "A" poles as for single poles, namely—

$$K = \frac{W\,L}{4{\cdot}7\,R_1^2\,R_2}.$$

For "A" poles loaded either in their own plane, *i.e.*, at right angles to the wires, or when loaded in the direction of the wires (but, of course, the values of K_A will not be the same in both cases), this becomes—

$$K_A = \frac{W\,L}{2{\cdot}35\,(R_{A1}^2\,R_{A2} + R_1^2\,R_2)};$$

or, when the poles are circular in section—

$$K_A = \frac{W\,L}{2{\cdot}35\,(R_A^3 + R^3)}.$$

A comparison of the values of K_A and K gives the relative strengths of an "A" pole and a single pole of the same size as one of the "A" poles. Whence—

$$W = \frac{2{\cdot}35\,K_A\,(R_{A1}^2\,R_{A2} + R_1^2\,R_2)}{L},$$

and—

$$W = \frac{2{\cdot}35\,K_A\,(R_A^3 + R^3)}{L}.$$

A comparison of the results obtained by the two expressions is of interest. Experiments show that $K_A = 4{\cdot}5\,K$ for poles in which the ratio $\frac{L}{S} = 8$ (see tables). Then $K_A = 5{,}850$ lbs. square inch.

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TABLE II.

L.	S.	$R_A = R$.	Calculated Strength. On the assumption that the Compression Pole buckles.	Calculated Strength. Deduced from K_A.
Inches.	Inches.	Inches.	Tons.	Tons.
240	30	3	1·3	1·4
		4	3·4	3·3
		5	6·8	6·4
		6	11·8	11·1
360	45	4	1·9	2·2
		5	4·1	4·2
		6	7·5	7·3
		8	18·6	17·4

It will be seen that the results are not in perfect agreement, but they are as good as can be expected from the nature of the experiments; they at least show that there is no very serious error involved in the assumptions.

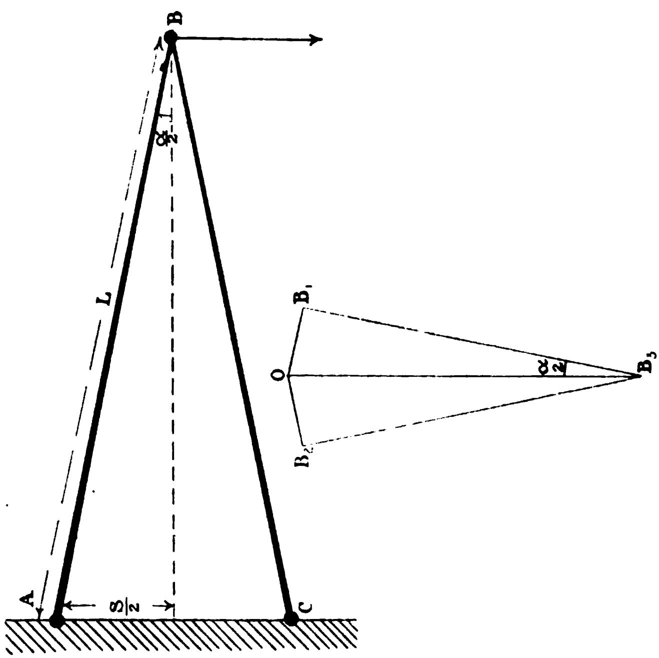

FIG. 22.

DEFLECTION OF "A" POLES.

The deflection of "A" poles is due to various causes: (i.) the extension and compression of the constituent poles; (ii.) the slip or shear of the apex joint, which is a very uncertain quantity and depends largely on the strength of the scarfed joint; (iii.) a small amount of bending of the poles. If the structure were a simple triangulated truss with pin-joints at the feet and at the apex, the deflection can be readily calculated by Professor Kernot's method, thus:—

On account of the extension of the member A B (see Fig. 22) the point B tends to move in an arc of a circle struck about the point C, and on account of the compression of the member C B the point B tends to move in an arc struck about the point A.

Draw $O B_1$ parallel to A B to represent on an enlarged scale the extension of A B; similarly draw $O B_2$ parallel to C B, to represent its compression; draw $B_1 B_3$ at right angles to $O B_1$, *i.e.*, in the direction of one component of the movement of B due to the shortening of C B; also draw $B_2 B_3$ at right angles to $O B_2$, then $O B_3$ sensibly represents (to the same scale as $O B_1$) the resultant movement of the point B. From the well-known formula for elastic strain we get—

$$O B_1 = \frac{L^2 W}{S \pi R_m^2 E} = O B_3 \sin \frac{a}{2},$$

but—

$$\operatorname{Sin} \frac{a}{2} = \frac{S}{2 L},$$

hence—

$$O B_3 = \frac{2 L^3 W}{S^2 \pi R_m^2 E}.$$

The deflection due to (ii.), *i.e.*, slip in the joint, can be arrived at thus:—

Let X = the slip of the joint, *i.e.*, the total movement of the one pole relatively to the other, then—

$$\frac{X}{2} = \frac{S . O B_3}{2 L},$$

and—

$$O B_3 = \frac{L X}{S}.$$

Hence, neglecting the bending of the poles, we may expect the deflection of an "A" pole to be in the neighbourhood of—

$$D_a{}^1 = \frac{2 W L^3}{\pi S^2 R_m^2 E} + \frac{X L}{S}.$$

On account of the complex bending action on the pole due to the scarfed joint and the central stay, the expression does not give altogether satisfactory results.

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For practical purposes it is more convenient to make use of the same form of expression as we arrived at for comparing the relative deflections of single poles, viz.:—

$$D_A = \frac{W L^3 d_A}{13{,}824{,}000 (R_A^4 + R_a^4)} \quad \left\{ \begin{array}{l} \text{when both poles are circular in} \\ \text{section and of radii } R_A \text{ and } R_a. \end{array} \right.$$

or—

$$D_A = \frac{W L^3 d_A}{13{,}824{,}000 (R_{A_1}^3 R_{A_2} + R_1^3 R_2} \quad \left\{ \begin{array}{l} \text{when the poles are not} \\ \text{circular in section.} \end{array} \right.$$

The quantity d_A is the deflection of a unit "A" pole 12 ins. long, 1 in. diameter when loaded with 1,000 lbs. at its extreme end, and is obtained from experiments on "A" poles, as explained above, for single poles.

If the deflection at the extreme end is required, we have, as before—

$$D_{Ae} = D_A \left(\frac{2L + 3T}{2L} \right).$$

This method of treatment is not altogether satisfactory, but considering the uncertainty of the joint and the possible defects in the timber it is probably as accurate as it is possible to get under the circumstances.

When "A" poles are loaded in the direction of the wires, the strength of the structure is twice that of a single pole of the same dimensions and material, and the deflection is one-half as great.

Wind Pressure on "A" Poles.

When the wind is blowing transversely to the wires the one leg of the "A" pole partly shelters the other, it is not easy to say exactly to what extent. We have assumed the wind pressure to be 1·5 times as great as on a single pole of the same size as one of the "A" poles. Hence the resultant wind pressure acting at a point 2 ft. from the top of the pole is—

$$\frac{1{\cdot}5 \left(\frac{R_A + R_a}{2} \right) (L_o - G)^2}{9{\cdot}6\, L} \quad \left\} \begin{array}{l} \text{where the poles are both circular,} \\ \text{and the radius of the one is R} \\ \text{and the other } R_a, \end{array} \right.$$

or—

$$\frac{(R_A + R_a)(L_o - G)^2}{12{\cdot}8\, L}.$$

The net safe load in pounds for an "A" pole, *i.e.*, the safe load it will support in the shape of side wind pressure on the wires, is, for a factor of safety of 10—

$$\frac{2{\cdot}35\, K_A (R_A^3 + R_a)^3}{10 (L_o - G - T)} - \frac{(R_A + R_a)(L_o - G)^2}{12{\cdot}8 (L_o - G - T)},$$

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Index.	Splay at Foot of Pole in Inches. S.	Overall Length of Pole in Inches. L_0.	Remarks.		
a	—	476	fir, not creosoted.	Single Poles.	
b	—	484	ditto.		
c	—	478	fir, creosoted.		
d	—	444	, not creosoted.		
e	25	384	ig. 9. No	Imperfect method of holding foot of pole.	"A" poles tested on edge, *i.e.*, at right angles to the wires.
e_1	25	384	three oak		
f	25	385	ig. 9. No		
f_1	42	385	ng out at		
g	24	436	chocks. Tension pole bolt hole at 2,050 lbs. n.		
h	36	432	ock. Failed by shearing beyond the oak chock.		
i	48	433	hocks. Failed by buck- on pole.		
j	48	435			
k	60	434	One chock. Failed by ion of the oak chock.		
l	72	433	hocks. Failed by buck- on pole.		
m	48	432	top end of the the buckling pole.	See Fig. 12.	
n	48	—	d by slipping	Fig. 14.	
o	48	433	nds and long d by buckling ole.	Fig. 15A.	
o_1	48	433	refitting and ailed by buck-	Fig. 15B.	
p	48	434	d by twisting ling the com-	Fig. 16.	
p_1	48	434	ing oak chock. e at the chock , of section.	Fig. 16.	
q	48	385	d, no scarfing by buckling.	Fig. 14 after refitting.	
e_2	25	384	by twisting oak chocks.		
e_3	25	384	itting new oak chocks. ing.		
e_4	25	384	poles tested on the flat, or in the line of the wires.		
f_2	25	385			

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and when the poles are both circular and of the same size we have—

$$\frac{4\cdot7\,K_A\,R^3}{10(L_o - G - T)} = \frac{R_m(L_o - G)^2}{6\cdot4\,(L_o - G - T)}.$$

The results of the tests are given in tabular form (Table III.).

From the above results we find that the mean value of d for single poles is 8·4 ins., and for "A" poles tested on the flat 4·3 ins., thus the deflection of similar "A" poles when tested on the flat is practically one-half as great as that of a single pole when similarly loaded, which is quite what we should expect.

Some of the "A" poles were tested with imperfect housings, and others were of a purely experimental character, some of which proved failures; taking an average value for such poles as are likely to be used in practice and when properly held at the foot, viz.: $g, h, i, j, k, l, m, o, o_1, p, p_1, q, e_2$, we find that $d = 0\cdot17$ in., or $\frac{1}{50}$th as much as that of a single pole. The highest value of d for an "A" pole when properly held was 0·36 in., or $\frac{1}{23}$rd; and the lowest value 0·069 in., or $\frac{1}{122}$nd as much as that of a single pole. The great variation is probably due to slip in the top joint. It is interesting to compare the calculated deflections for 1,000 lbs. with those actually recorded.

TABLE IV.

Pole.	By Experiment.	By Calculation.
g	2·15	4·0
h	2·13	1·5
i	1·02	1·0
j	1·02	1·0
k	1·25	0·7
l	0·61	0·8
m	0·50	0·9
o	0·73	1·0
p	1·08	0·8
q	0·72	0·6
e_2	0·45	0·4

The two results cannot be said to agree well, but when it is remembered that there are so many disturbing causes a good agreement is perhaps hardly to be expected. The value of E has been taken as 1,000,000 lbs. per square inch.

The curves given in Figs. 23 and 24 show clearly the manner in which the deflection and the slip of the top joint varied with the load.

As regards the relative strength of single and "A" poles, the mean value of K^A as deduced from poles of practical design, viz., h, i, j, k, l, m, o, o_1, is 5,748 lbs., or 4·42 times as great as the Post Office value for a single pole. As already pointed out, the majority of poles failed

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through the buckling of the compression leg; this buckling was undoubtedly hastened by the initial sag in the poles due to their own

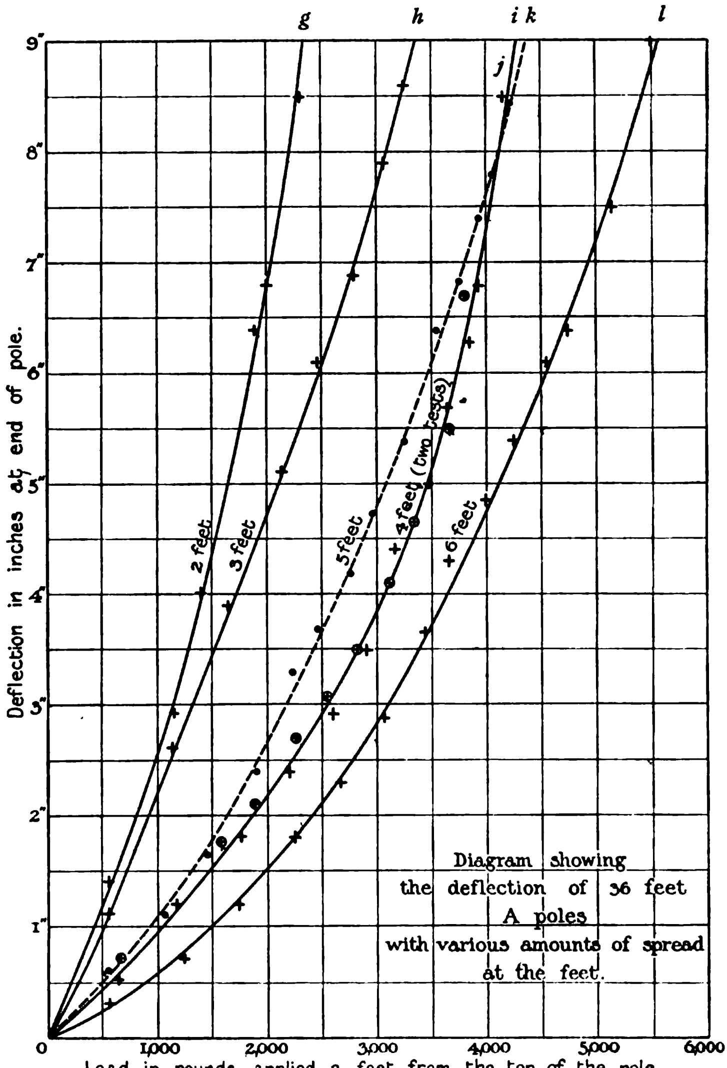

FIG. 23.

weight, which, of course, will not occur in practice where the poles are set in a vertical position, hence it is considered safe to assume that "A" poles are about 4½ times as strong as a single pole of the same size.

It is of interest to note the load on the compression leg of the poles when buckling took place. (See Table V.)

I am fully alive to the defects of some of the methods I have

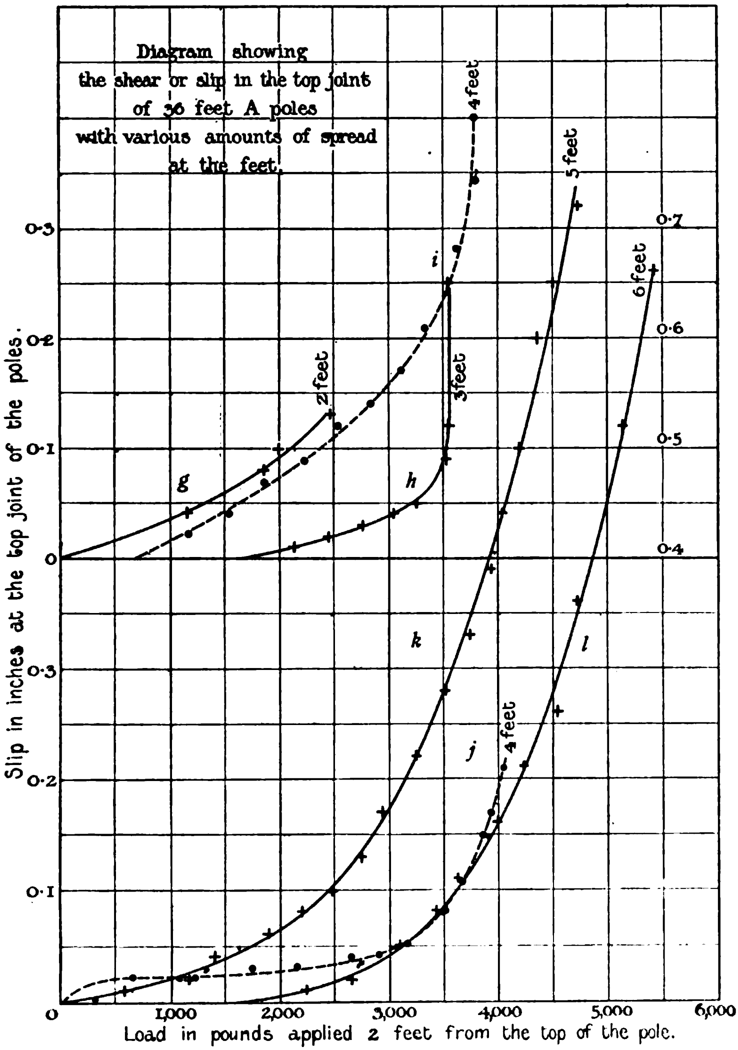

FIG. 24.

made use of in attempting to arrive at a theoretical basis for the strength and elasticity of the various poles treated in this appendix; I would, however, point out that this is believed to be the first attempt at

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getting any experimental or theoretical data upon the question. I trust, however, that the data given may serve as a useful guide to electrical engineers who may be engaged on the design of overhead lines.

TABLE V.

Index.	Splay in Inches.	Force in Tons acting on the Compression Pole when Buckling occurred.	
		Experiment.	Calculated.
i	48	14·4	12·8
j	48	13·2	12·6
k	60	14·8	13·0
l	72	12·2	12·6
m	48	12·7	13·4
o	48	12·0	11·9
o_1	48	13·7	11·9
q	48	16·0	18·0

DISCUSSION.

Professor Goodman.

Professor GOODMAN: I think we must one and all admire the enterprise of Mr. Wade in undertaking this series of tests, on which he has spent a large amount of time and labour; he has to my knowledge made many experiments in addition to those recorded in the paper. I also think we must admire the generous way in which he has placed all these results at the disposal of the members of this Institution, which is an act of courtesy worthy of the highest tradition of our profession.

One of the most important points he has raised is that of the loads that come upon telegraph wires and poles. The weight of the cables themselves is, in general, quite a negligible quantity, except when a set of the wires is broken, as was shown in one of the slides. The only load that one need trouble about in ordinary design, excepting in the special cases of corner and angle poles, is that of the wind. The members are perhaps aware that the Board of Trade insist on a very high wind pressure being allowed for, namely 30 lbs. per square foot, and further, they insist upon a factor of safety of 10. Everyone will admit that it would be an extremely dangerous thing if an installation of this kind came over, and the wires carrying high-tension currents were dangling about over the heads of people, and perhaps trailing on the ground as they passed along the roadway. The Board of Trade, in the

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Professor Goodman.

early days of overhead transmission, insisted upon this very high factor of safety, and I think wisely, because until these tests were undertaken by Mr. Wade practically nothing was known about the strength of A poles. A good deal was known about the strength of single poles, but practically nothing about A poles. Now that we do know something about them—I will not say everything, but we do know within a comparatively small margin what loads such poles will carry and how much they deflect—I think we may justly plead with the Board of Trade to give us somewhat easier terms. A wind pressure of 30 lbs. per square foot on wires and poles is probably somewhere near the mark in a very exposed position near the sea-coast, but any one who has gone into the question of wind pressures knows that such pressures are never recorded in inland towns and districts. Sir John Wolfe Barry has said, on more than one occasion, that he has never recorded even 5 lbs. per square foot on the bascules of the Tower Bridge, whereas, on the other hand, Sir Benjamin Baker has recorded nearly 40 lbs. per square foot on the Forth Bridge. I think we may therefore ask the Board of Trade to deal with each installation on its own merits. If an overhead line is to be erected in a very exposed position near the sea, then insist on the 30 lbs. wind pressure; but if in an inland place where it is well sheltered allow, say, a pressure of 10 lbs. per square foot. Since we do know within a little the strength of these poles, may we not also ask them to allow us to use a smaller factor of safety than they have done in the past? I think it was wise in the extreme that they insisted on a high factor of safety in the past, but I do think they would not be running any undue risk if in the future they permitted a somewhat lower wind pressure and factor of safety to be adopted. Twelve months ago, when Mr. Wade undertook these tests, practically nothing was known about the strength of A poles. If any engineer or expert in the construction of timber had been asked to give his opinion as to how these poles would fail, I think he would not have predicted that they would fail in the first place at the top joints and afterwards by the buckling of the pole, although when one comes to look into the question from a purely theoretical point of view, we find that such is approximately what we ought to expect. I have attempted in the Appendix of this paper to analyse the stresses and the deflections of these A poles with a certain amount of success.

It must be remembered that no two poles are exactly alike; the timber itself varies; its properties depend somewhat on whether it is green or well seasoned, and the strength also depends upon the manner in which the poles are fitted together. Therefore I think the theoretical results that I have obtained may be regarded as fairly well agreeing with the experimental results that have been obtained by the author, and are quite as near as we can expect under the circumstances. I have made a great many inquiries with regard to the failure of poles of this type, and have not been able to discover more than two or three isolated instances in which such poles have failed by breaking; but I have come across, I think I may say scores, perhaps hundreds, of

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Professor Goodman.

cases where they have been uprooted. I therefore think the main point that should be borne in mind in the design of overhead transmission work is to pay even more attention to the foundations of the pole than to the pole itself. Of course the pole itself must be carefully considered, but the foundations must also be carefully attended to. You will be much interested, I am sure, in seeing from these tests of the author that the compression pole buckled in almost every instance. If we could only stay that compression pole to prevent the side buckling, then we should probably treble or quadruple the strength of such poles. It could, of course, be done by putting stays on the side of the pole to prevent buckling, but it would be unsightly and at the same time costly. With regard to H poles, I have not yet had the opportunity of testing any, but the question of testing some models has been discussed. In the case of the H pole, I believe we shall not be troubled with the buckling until much higher loads are reached than obtained in the case of A poles. I cannot go into the details, but theory points very much in that direction. I would like to point out one very bad piece of design in all the H poles: I refer to the central ring to which the bracing bars are attached, which is a very weak spot. The type of bracing to which I refer contains a ring in which there is a pull in two diametrical directions at the same time. Experiments and theory both show that such a ring passes the elastic limit at a very low load. Such bracing might very easily be improved at no great increase, if any, in the cost. The H pole offers a rather greater wind resistance than the A pole, probably in the neighbourhood of 2 to 1½. We have assumed that the wind pressure on an A pole is 1½ times as great as that on a single pole. Those who have had an opportunity of studying the interesting paper recently read by Mr. Trotter before the Institution of Civil Engineers will be interested in his calculations on the bending stress which occurs on the poles when the wires are accidentally or intentionally broken. You are, perhaps, aware that when a fire occurs in a city the firemen often have to cut the wires for getting the fire-escapes into position. The poles on either side bend over away from the loose ends of the wires; the loads on the poles are relieved to a certain extent by the deflection of the distant poles, but the stress, even in spite of the greater sag of the wires, may be very high. It is interesting to know how the load on the poles on such an occasion compares with that due to wind pressure. I have calculated it out for the case that Mr. Trotter gives in his paper, and I find that the stress on the pole when an accident of that kind occurs is almost exactly twice as great as the stress due to the wind on the basis of 30 lbs. pressure. Hence, under ordinary conditions for a single pole there is no need to make any special allowance for the somewhat remote possibility of all the wires being cut or broken. The dynamometer used in these tests was similar to an instrument used for measuring the stresses in the members of girders. It is of a very simple construction, (Fig. B) but very accurate.

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Two heavy bars of steel are bent round to the form shown. A Swiss watchmaker's micrometer A, capable of reading to 10,000ths of an inch, is attached to the bars by means of the bracket B. When the dynamometer is pulled the bars are distorted and turn the micrometer pointer. The deflection of the instrument can be calculated, but there might be some uncertainty as to the accuracy of the calculation, therefore the instrument has been graduated in a testing machine, from which we find experimentally the load corresponding to the given graduations on the dynamometer. Under ordinary conditions it can read it to within about 2 lbs. Thus when dealing with loads up to 3 tons on the dynamometer, the proportional accuracy is great. For bigger loads up to 5 tons a big helical spring was used and the load was measured by the deflection, the calibration of which had also been done in a testing machine. With the latter readings could be taken to within 20 lbs., which is a very small amount when Professor Goodman.

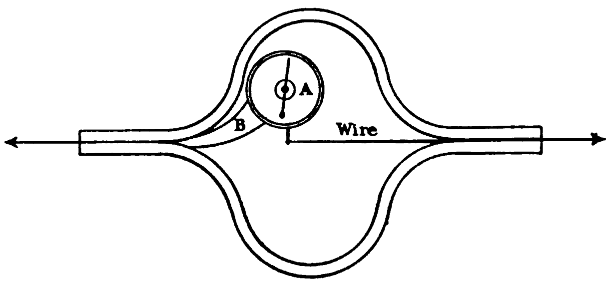

FIG. B.

dealing with 4 or 5 tons. I think the loads obtained with the dynamometer can certainly be trusted within a few pounds.

The method of getting the deflection of the poles by means of a telescope was also, I think, quite accurate. As Mr. Wade has pointed out, it is extremely important when making tests of that kind to use a telescope, because, however careful you may be and however rigid you may make your housing, there is certain to be some slip of the pole in the housing, which comes in as an error in the measurement. But by using a telescope, and by shifting the zero each time, you eliminate that error. I am inclined to think from the manner in which these results are plotted, and from the manner in which they fairly well agree with the calculated values, that our results were quite as near as it was possible to get with experiments of this kind.

Mr. C. WADE: I should like to say that the reason we did not take more tests of single poles was that they practically carry no load at all. I have figures here prepared by Professor Goodman, from which it can be seen that the single pole practically bears very little load and is Mr. Wade.

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Mr. Wade.

quite useless, and that an A pole can be produced very much more easily which will carry a bigger load at far less trouble and cost. I should also like to say that in these tests the method of holding the A poles was very much more rigid than it would be in the usual way when they are put up in the ground, and it is probable, I think, that if they had such loads put on them as were put on them in the tests they would come clean out of the ground. I think Professor Goodman will agree with me that our results might have been taken as being very much higher if there had been a little give in the housing—if the poles had not been so tight that they could not move at all.

Major O'Meara.

Major W. A. J. O'MEARA, C.M.G.: I see that on page 305 the author makes a statement that "there were no reliable data from which to settle the requisite strength and size of poles employed," Professor Goodman has corrected that statement, and I therefore hope that Mr. Wade may have overlooked the existence of a small pamphlet entitled "Technical Instruction XIII." * that has been used for many years at the Post Office. Its last revise is dated March, 1906, and a copy can be obtained by anybody for the price of 1s. 6d. from the Stationery Office. In that pamphlet will be found accumulated the experience of the Post Office during the last thirty-seven years, and the members will probably be struck by the similarity of many of the engravings with those that appear in this paper. We have not carried out any experiments very recently—in fact, all the tests with full-sized poles were carried out in 1885—and we have not really paid any more attention to that subject, because we were quite satisfied from actual experience with the results which we then obtained. I do not say that our construction comes up to the standard of the Board of Trade, because our factor of safety for wires is only 4, and for other parts of the structure 8, but our single pole lines, though they do not appear to give very much satisfaction for power purposes, give very much satisfaction to us. We are able to carry from 48 to 60 wires of varying gauges, from 4½ S.G.W. down to 16, on such lines. We have ourselves fully realised the advantages of an A pole. In the old days of telegraph wires we used A poles to a very great extent. Even when the lines were in a straight run a certain number of A poles were always put in position, because it was felt that they added to the stability of the line. The great enemies to the telegraphs and telephones are trees and clinging snow. We do not get very much disturbance from wind, but we certainly get a great deal of disturbance from trees. In all my experience, though I have seen many miles of telegraph and telephone wires down, I have never seen a broken pole yet, but, as Professor Goodman remarked, it is the foundations that give way. The poles are nearly always pulled out of position first; the binders give way, and the wires break and run back. There is only one more point to which I would like to call your attention. I have placed on the table samples of telegraph poles which have recently been cut down during renewals. I see that Mr.

* The full title of the pamphlet is "The Construction of Aerial Lines on Roads and Railways."

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PARTICULARS OF SOME RENEWALS OF DEFECTIVE POLES.

Locality.	Class of Pole.	Date of Erection.	Date of Renewal.	Life.	Reason for Renewal.	Remarks.
				yrs.		
Ireland	Creosoted.	1872	1906	34	Broke off below ground line.	No appearance of rot above ground line or at arm slots. Majority of remaining poles still hard. Line erected about 1870.
	Light and Medium.	1878	1906	28		
Between Wells and Blakeney (Norfolk).	Creosoted Light.	1870	1906	36	Unsafe at top owing to long exposure near sea.	Poles 22 ft. and 24 ft. Sound below ground line.
Kessingland to Benacre.	Creosoted Medium.	1882	1907	25	3 poles, 1 decayed at ground line, 2 at arm slots.	About 60 poles examined, all found to be sound with the exception of those named, which were erected at the same time.
Stevenage	Burnettised.	1885 (about).	1892	7	Badly decayed.	Others erected at same time were then quite good.
Chesterton (Cambdge).	Do.	1898	Probably 1908	10	Decaying 5 poles.	
Chesterton (Cambdge).	Do.	1898	1907	9	Decayed.	This pole rotted almost through below ground line to 5 ft. above, but leaving hard shell of wood all round.
Kelvedon (Essex) ...	Do.	1895	1907	12	Decayed.	This pole broke off at the ground line on April 26, 1907. It was sound for a diameter of about 4 inches at the centre, but decayed outside.

PARTICULARS OF SOME RENEWALS OF POLES FOR REASONS OTHER THAN DEFECTS.

Locality.	Class of Pole.	Date of Erection.	Date of Renewal.	Life.	Reason for Renewal.	Remarks.
Peterboro Section East Coast Line.	Creosoted.	1883	1907	24	Too light or too short.	Still in good condition.
Hunstanton	Do.	1872	1907	35	Too short.	

PARTICULARS OF POLES STILL IN USE AND IN GOOD CONDITION.

Locality.	Class of Pole.	Date of Erection.	Date of Renewal.	Life.	Reason for Renewal.	Remarks.
Cambridge Section...	Creosoted Light.	1872	Still in use.			Poles in various localities. Appear to have years of life left yet.
Stilton Doncaster Line.	Creosoted Stout.	Prior to 1878	Do.			Show no signs of decay.
Ipswich Section ...	Creosoted.	1873	Do.			Poles in various localities. Large number of this date have also been renewed owing to their being too light, but not on account of decay.
Ipswich Section ...	Iron.	About 1870	Do.			Erected by the Royal Engineers about time of transfer of telegraphs to the State in 1870 and still good for long life. Only renewed when too light.

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Major O Meara.

Wade gives creosoted poles a life of fifty years. I am afraid that is not our experience. The German Government have published the results of their experience over fifty-two years. ' They find that creosoted poles last on an average for twenty and a half years. Our experience has been more fortunate than that. I do not say that individual poles do not last fifty years, but we have no experience of that. We have a few creosoted poles at the present time which have been in existence for forty years. Our trouble really arises from the fact that, in the old days, we did not realise the rate at which the telegraph business would grow, and therefore we have had to replace our poles simply because they were not long enough to carry the number of wires now in use, and in many cases also we have been disturbed by tramway undertakings. As the poles taken down have but a very short additional life in them, we do not find it economical to re-erect these poles in every case; they are therefore abandoned, and replaced by new poles. I certainly think that everybody who wants his balance-sheet to come out on the right side should adopt a very much shorter period than fifty years for the basis of his renewal fund.

Communicated:

Burnettised Poles.—These poles have an average life of from seven to ten years, but are very unreliable, some decaying after being erected three or four years. Two examples have been brought under notice, one in which the decay commenced at the centre and spread outwards, and the other in which the opposite result was experienced, the centre being sound for a diameter of 4 inches.

Boucherised Poles.—Unreliable. Average life twenty to twenty-five years. Frequently found full of wet rot below ground whilst upper part is perfectly dry.

Creosoted Poles.—When properly seasoned before being creosoted, individual poles will last thirty to forty years.

The rot takes place in the inside whilst the shell remains good. The poles are quite good provided the shell remains two to three inches thick.

The nature of the soil has a bearing on the life of the underground portion of creosoted poles; thus:

Clay and chalky soils tend to prevent the loss of creosote and so preserve the timber.

Sandy soil allows the preservative to escape and dry rot is likely to set in, reducing the life to fifteen years.

Boggy land, especially if iron ore be present, reduces the life to fifteen or twenty years. In one such case in County Donegal renewals were necessary after seventeen years.

Mr. Trotter.

Mr. A. P. TROTTER: I would ask you to accept my remarks, as usual, as purely personal and unofficial. Seldom in the history of engineering, I think, have destructive tests been carried out by a private firm on so large a scale, involving such quantities of valuable stock, and other expenditure. Scientific tests of timber have been made by the

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Forestry Department of the United States and a paper was read by Sir William Preece in 1885 before the British Association on a series of tests, carried out largely by Mr. J. Gavey, upon Post Office poles. I was familiar with those tests, and had studied them when I suggested to Mr. Wade that further tests would be useful. One reason is that Post Office practice ends in some respects where electric transmission practice begins; the work is very much heavier. The second reason is that the questions of safety are obviously of much more vital importance. When Mr. Wade wrote his paper there were fifty miles of overhead transmission line in this country. I think there are more than sixty or seventy at work now. Certainly more than fifty miles of line have weathered this last winter, and, as far as I have heard, not a single accident of any kind has occurred. There were some heavy gales, and you remember the results of the very considerable snow-storms that occurred. This success may mean that the factor of safety is too big. There may be a margin, and the question is what that margin is. Professor Goodman has pleaded for an extension of factors of safety and a reduction of wind pressure. Such reduction has been made, and if evidence of it is wanted I would call to mind the first and the last of the photographs shown upon the screen. The first poles were put up under the erroneous impression that some old regulations of the Board of Trade for low-pressure overhead wires were intended to apply to modern work. Those old regulations have been untouched for many years; they were made I do not know how many years ago. They asked for a wind pressure of 50 lbs. per sq. foot, and a factor of safety of 12. When the time came for extra high pressure transmission lines, those who looked into the matter carefully were aware that there were no regulations for such lines, and that each case was dealt with on its own merits. That means a lot of work. However, the cases were looked into, each one on its merits, and for some time past a factor of safety of 10 was adopted for wooden poles and a wind pressure of 30 lbs. per sq. foot. I think that is already a considerable reduction, 50 to 30, and 12 to 10. What is a factor of safety? It is almost unknown among continental engineers. They work with a maximum permissible stress; and where we take the breaking stress and a factor of safety of 10, they take one-tenth of the working stress and call that the permissible working stress. It is exactly the same thing. A factor of safety has been called a factor of ignorance, and therefore it logically follows that anything which can be done to decrease our ignorance should decrease the factor of safety. Ignorance obviously has been largely decreased by the efforts of Mr. Wade and Professor Goodman. If we were dealing with material like steel, it would be right to reduce the factor of safety, but, as has been just said, timber varies. One pole is not like another in quality; knots and various irregularities will occur. It has been the engineering practice in this country during the last fifty years to adopt a factor of safety of 10 for wooden structures. I have searched through all sorts of books, the oldest books and the modern books (the modern books are only

Mr. Trotter.

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Mr. Trotter.

copied from the old books), and I cannot find any engineer of repute who has suggested less than 10 for a timber structure. It may be said that these things are hardly structures, that they are simply poles as provided by Nature, with as little work as can possibly be put on them. There is something in that. The Post Office have allowed a much smaller factor of safety; but a study of that most useful and inexpensive handbook of the Post Office will show that they take a certain number of things into account. For instance, tall or exposed poles are given a larger factor than 8, and where the line is sheltered from the wind the factor may be slightly reduced.

There is just one thing I see Mr. Wade has not mentioned: he does not say what his poles are made of. I believe they are red fir. That is rather an important matter. In the Post Office book there is a specification, which is an excellent one and should be followed, for the Post Office poles, and there it will be seen that they are all red fir. Larch has been used in one line in this country, and various kinds are used in America, where they are already exhausting some of their stocks of wood. The life of a creosoted pole has been alluded to as fifty years. That is probably putting it rather too long; but even if taken at thirty years the question is, Did they understand thirty years ago the modern process of injecting creosote in the very perfect manner that is carried out now? I rather doubt whether these poles of thirty years ago were injected as the modern ones are. I was not aware that they had creosoted poles in Germany, and I should like to know whether the process of creosoting is anything like as good as the modern English process. I say I was not aware of it, because in looking in the Journals for the last few months I have seen paragraphs about the life of wooden poles, and mentioning all sorts of chemicals which give a life of five or six years, if I remember rightly. With regard to America, the very latest books I have seen on pole-construction do not mention creosote.* Each case is at present taken on its merits. It is a little difficult, I think, to take wind pressure in each case from information received, but allowance surely should be made for a well sheltered line. I think Mr. Wade has been misunderstood in his statement that single poles are no good at all. Perhaps I may explain what I believe he means, and that is that from an economical point of view, if it is desired that a pole should stand a certain stress, to carry certain weights and certain wind pressure, it will be found a single pole is out of the running from the point of view of cost compared with an A pole. Even if the factors of safety are not too high—I grant they are rather high—it will be necessary in the case of a good

* Dr. F. A. C. Perrine says: "In some places the poles which are available have a life no longer than about five years, and in the extreme wooden poles cannot be greatly depended upon for a period greater than fifteen years." J. F. Kelley and A. C. Bunker write: "One six-year-old redwood line with butts treated before raising had to have 33 per cent. stubbs. Another redwood line, untreated, had to have 10 per cent. stubbs in three years. Another line of untreated cedar poles required 35 per cent. stubbs in six years." Mr. B. J. Arnold says: "Fifteen years is assuredly the maximum limit." In Utah, Mr. F. O. Blackwell says that "wooden poles have a life of not more than ten years; many last only five years.'

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heavy line, say a six-wire route, with fairly large wires upon a single pole of a height just to clear the traffic comfortably, say 18 ft. or 20 ft. from the ground, to take a big tree and saw off and waste the top half of it. Therefore, from an economical point of view it is far better to have two small poles, build an A pole, and it will be found that on those grounds the single pole is out of the running on account of cost. This applies to the heavy lines we are speaking of. It is easy to see that the Post Office and the Telephone Company can very conveniently and properly use the single pole. The case mentioned by Mr. F. Gill, one hundred wires on a pole 70 ft. high, might doubtless be a case for a single pole. But the poles which formed the subject of the present discussion were only 32 ft. over all, and carried at the most six wires. The conditions were very different. Mr. Trotter

Mr. F. GILL: I think it is a very satisfactory thing indeed that we have obtained from the author what one may call life-sized tests. They are not tests made on small pieces, but tests made on the real article. One thing I think has been successfully achieved, and that is if anybody had doubts as to the suitability of wooden poles for transmission work they ought to have them dispelled by this paper. Mr. Gill.

On page 321 Professor Goodman describes the letter "T" as "the distance in inches from the top of the pole to the point of loading in the actual pole tested. In the tables this is taken as 24 ins. throughout." In Table III. we have quite a varying number of inches in "T"—26, 27, 23, 29, and so on. Probably I may be reading it wrongly, but I shall be pleased if Professor Goodman will give the corrections. Table V. is likely to be very valuable for the information it gives on compression stresses, which personally I do not remember having seen before. With regard to Mr. Trotter's remarks, I have not made any calculations, but I believe I ought to feel that if a telephone company wants to carry, say, one hundred wires on a pole 70 ft. high it cannot carry them on a single pole. That is the way I rather read some of the remarks that have been made. I think the answer is, It does. Some of the reasons why telephone people, at any rate, have not gone in very much for A poles are the features incidental to the work. For one thing, we have to consider arm space. We have not only to get up a pole, but to get up a structure which will carry a number of wires, and therefore the arm space is a very important point, and has a great bearing on the cost per wire. Then with regard to the question of twist (*i.e.*, rotation of wires), an A pole is an awkward thing for twisting. Then there is the question of hedges to be taken into consideration. We can get a single pole along a road in many cases very much easier than we can an A pole. The next point is the question of wayleaves. Transmission engineers will run up against wayleaves pretty soon, I hope—the sooner the better—because some of us have struggled against wayleaves for years, and we shall be delighted to have a good solid backing of other people's opinions to help us. Then with regard to stays, the base of a structure consisting of a single pole and stays is more flexible than an A pole, and can con-

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Mr. Gill. sequently be more easily varied to meet local conditions. Mr. Wade suggests that other countries are ahead of us. I would like to refer to a picture in Mr. Highfield's paper of a pole-line in France. It was not all A poles, and I do not believe it had a factor of safety of 10, and I do not believe the pole-line that was erected for £160 a mile which Mr. Wade mentions had a factor of safety of 10.

I had noticed myself that in Germany, Sweden, and France the poles seem to be a great deal lighter than they are in this country; but of course I am not pleading for bad work. Professor Goodman mentioned the question of the ground in which the pole is to be set. In that connection it seems to me an A pole may be more unsuitable than a single pole stayed. An A pole is practically put into a trench and punned in; it is all disturbed ground. When the stress is severe, the pole may be pulled out of the ground without in any way damaging the structure; that has been done in many cases. If, however, a single pole stayed is considered, that pole goes, so far as side stress is concerned, into new ground. The stay also pulls against new ground; and I think it will be found that the holding power of a single pole stayed is possibly superior to the holding power of an A pole. Major O'Meara mentioned the German Government Report with regard to the life of creosoted poles. I think the German Government Report, as far as I read it, is unsatisfactory. They carried their tests a certain time, and then they stopped them for some reason and apparently assumed that those poles which had not then lived to the end of their lives would live as long again, and so they got an average life.

As regards the question of economy; we have, as we so often have at this Institution, the question of economy discussed in connection with the question of first cost. The first cost is not the test of economy; it may be an indication of what the economy is, but it is not necessarily so. The only true test of economy is the annual charge. I asked Mr. Gall and Mr. Shackleton to make two calculations for me, and I give very roughly the results. In the first case a certain stress was assumed on the poles, and to meet that stress it was calculated that we should put up either a 30 ft. pole (stayed against the stress) which was 7 in. in diameter about 5 ft. from the butt, or an A pole. Under these circumstances the capital cost (although, as I say, this is no criterion) came out relatively at 100 for the A pole, and 55 for the single pole—cheaper in first cost for the single pole, but I do not attach any importance to that. Taking the annual costs, and after giving due consideration to the fact that a stay-rod and rope will not last as long as a pole, and have to be renewed earlier, we arrive at the relative annual costs as follows: the A pole 100 and the single pole stayed 73. That, I think, is a fairly true measure of the economy of the thing under those conditions. In the second case, an A pole and a single pole were taken, the single pole being stayed on each side to give it transverse strength equal to the A pole, although it was not needed. Under those circumstances we obtained these relative figures.

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Mr. Gill.

The capital cost of the A pole was 100, and the single pole, double-stayed, 80. When the annual costs were taken into consideration they came out equal. In that case the poles were equal in strength, at right-angles to the line, but in the direction of the line the single pole was stiffer. In these figures of annual costs, wayleave was not taken into account; each person must get his own figure as regards wayleave. They include depreciation, maintenance, and all the annual charges. I am not therefore at all clear that the economy of A poles is necessarily demonstrated; we may be putting in strength in a transverse direction which may not be required.

Mr. Chamen.

Mr. C. H. K. CHAMEN: With regard to the factor of safety, I should like to point out that in every case the whole thing has been taken on the safe side. If the factor of safety cannot be reduced below a figure of 10, it might be taken into account that no pole that was supposed to be tested to destruction was really destroyed in the sense that it would drop the line. It would have had to be replaced at some future date, but it would not have let the line down. I do not know how much importance can be attached to the fact that in all the A poles tested there was an initial sag in the compression member which gave it a start. If the pole had been vertical it would not have had any sag; it was simply because it was lying on the flat that the compression member was sagged down. Professor Goodman will know what value can be attached to this. Mr. Wade stated in his paper that the A poles show their weakest points near the top. That is purely a question of shear and does not affect the dimensions of the pole. What a mainsman wants, whether he can have it or not, is a small pole; he wants things that a few men can run about with and put up in the ground quickly. Professor Goodman suggested that the factor of safety might be made less for certain special lines, and no doubt it would be very useful if that could be so, but the sort of thing that is wanted is that when there is a chance of a possible load a line can be erected cheaply and quickly. If the Board of Trade has to be specially negotiated with about any particular line before permission can be obtained to work it, the consumer will be lost. There is also the fact that lines are often wanted to be run to take up temporary loads; for instance, such things as the construction of reservoirs, or railways, or even sinking a well. All that work can be taken up and made to pay if material can be made light enough to be dealt with by a few men and a barrow. Rather than have such heavy poles, I would almost sooner put two A poles each of half the section in one hole. The separate members can then be made light, and they can be easily handled. It is not only the cost of the pole that has to be considered, although the extra cost of the heavy pole is very great, but it is the loading and unloading at the railway station, the hauling of the poles across country, over hedges and ditches and all sorts of places, that make erection so costly. I believe it will be found that two light A poles can be put up together to get the requisite strength, and will be cheaper. With regard to what Mr. Gill said about stayed single

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Mr. Chamen.

poles *versus* A poles, what will the authorities and the owners of the land say to this? It is to avoid the stay that an A pole is used. There are so many things that are all working together to hit overhead transmission which seem so unnecessary that it is almost absurd to pitch on any particular one to grumble at. Take, for instance, the square poles, of which Mr. Wade showed us a photograph. I suppose some Borough engineer thought that trees looked prettier if they grew square. That is all that can be supposed. The pole is weakened by a good deal more than the extent to which the sectional area is reduced; the thing looks very ugly and it costs more than double. I do not know whether Mr. Trotter can do anything for us in the way of reducing the cost of road-crossings. It is not only the cradle that is expensive, it is the pole on each side of the roadway. I would also like to suggest that the factor of the safety must be a bit lowered with regard to the poles that are supporting that cradle. It cannot be quite the same there as it is on the rest of the line. I am inclined to think that very probably those cradles will prove, in the course of years, rather more a danger than a safety.

Mr. Greene.

Mr. C. J. GREENE: I should like to add my appreciation of the tests carried out by Mr. Wade and Professor Goodman. Now we have them I think they are most valuable, because in putting up an overhead line I suppose engineers have to contend with almost more difficulties than in any other work. We have difficulties from the water in the earth, from the rock which we come across, difficulties from the wind, from snow, from lightning, and all sorts of natural causes. Therefore, the more we know about the strength of our raw material, especially the poles, the better. A good deal has been said about stays and the relative merits of A poles and single poles. I am quite of the opinion that an A pole is essentially the thing to put up. When stays are used, many difficulties are experienced. The author had two photographs which were shown on the screen of four-member poles, the latter one of which was, I believe, called "the one-horse line." The first of those poles showed two stays fitted to the four-member pole, and the second one showed two struts. The second one was intended to be put up with stays, but when the stays arrived on the ground it was found there was a cabbage-patch in the way. The stays, therefore, had to be scrapped, and two strutts put up at very short notice in their place. That is but one of the many difficulties we come across in the construction of these overhead lines. Other difficulties that we come across are due to railway companies, to the National Telephone Company, to the General Post Office, to consulting engineers, and also to resident engineers. Speaking of the difficulties experienced with consulting engineers, we have received from them schedules in which everything has been specified, down to the shape of the screw thread on the bolts which hold the insulator. In other cases we received merely 6-in. ordnance maps with a thin red line marked on them, and were told to put up the overhead line as shown on the plan. Of the two cases the 6-in. ordnance map with the thin red line is to be pre-

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ferred. Another point in connection with the erection is the ground in which the poles are set, and here again great difficulties occur. We have just put up a line where I remember that, after our engineer had dug the hole, he wrote a letter to say that the Railway Company wished the hole to be placed in another place, the resident engineer wished it placed in a second place, and the Post Office wished it placed in a third place: what was he to do? In the meantime water filled up the hole he had already dug. These instances give an idea of a few of the difficulties, from the contractor's point of view, in the erection of overhead lines. Coming to the serious part of the paper, I think first of all we have found out a law with regard to the breaking of these poles. It would appear a simple thing to have foretold how a wooden pole would break. We all know the formulæ and diagrams in text-books, where you fix a cantilever at one end, load it on the other, and expect the thing to break off clean and sharp at the point where the pole is fixed into the wall. Nothing of the sort happens when we test poles practically. If we test a single pole, we find it does not break off at the point of support; it breaks off somewhere about 8 ft. above the point of support. This seems rather a curious thing, and I have not seen an explanation of it. I am inclined to think that the fibres of the wood receive some sort of local support from the ground in which it is set up to a certain distance from the ground. Coming to the question of the top of the A poles, this is evidently the place where the poles fail, due no doubt to the buckling of the compression member. I notice that on page 312 two flat pieces of iron are shown at X and Y to prevent the buckling. I do not think the flat pieces as shown are much good; I think it is much better to put in two pieces of angle iron, which are so arranged that you get one web in tension and one in compression, which will assist materially in preventing the compression pole from buckling. As far as the top of the pole goes, I think the less we do in cutting it away the better. Whether we put in wood chocks or extra bolts, the strain is so great that the tension or compression per square inch on the wood of the pole surrounding the bolt is great enough to cause the bolt to actually crush into the pole. I think the best thing to do is to make a light slot for both arms and put a band round them, rather than bore bolts through the pole itself. Another very useful thing these tests have done—in fact, it was one of the reasons why they were carried out—is to show the correct splay at the bottom of the pole. Here we get into the problem of maxima and minima. As the splay is increased the cost of the pole goes down, but at the same time the cost of the excavation goes up. We find with ordinary poles about 32 ft. long the ratio of 8 to 1 in the height to the splay is a very convenient and sound thing to work to. Mr. Greene.

Mr. W. A. CHAMEN: I should like to assure Mr. Gill that in connection with wayleaves we do not appear to have much left to learn. We have met with all conceivable difficulties already. Power transmission engineers wish they could be allowed to run their lines along hedgerows beside roads. Our trouble is that we are not allowed to go along Mr. Chamen.

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Mr. Chamen. the roadsides. It may be that that is one reason why we do not find the single pole so much preferable to the A pole. In the places where we have to go over mountain tops and wild country there is plenty of space for the A pole, which generally requires no stays. We have not done much in the way of overhead lines in South Wales at present. One of the photographs on the screen showed the South Wales Power Company's line over the Gelli mountain. We have erred in that line through our desire to be on the safe side. The poles are all A poles, about 7½ in. or 8 in. in diameter at the top, and about 12 in. at the bottom. The line is about 20 ft. above the ground and the pole is not more than 31 ft. over all. The conductors in that case are three in number and of 0·15 square inch section each. There is no doubt whatever that the line cost a good deal more than it need have done. The photograph shown on the screen of the slope up the side of the mountain happens to be the easier one of the two. The other side of the mountain is much steeper. It was a matter of great difficulty to get the poles up at all. The cost of constructing these lines would be very much reduced if light poles could be used. We did not know what size of pole it was necessary to use, but we wanted to be safe, and there is no doubt whatever that we are quite safe. With regard to the life of the poles, I am sorry the Engineer in Chief of the Post Office did not tell us where they fail. Is it at the ground line, is it where the cross arms are let in, or is it at the top? Mr. Wade suggests that the places where the pole is cut should be very carefully tarred. Would it be possible to standardise the construction of A poles so that they can be dealt with after the manner of railway sleepers, which I noticed recently seemed to be cut, at the place where the chairs go on, to a standard thickness. Would not it be possible to put these A poles into some sort of machine gauge, have them all cut down at the top to the proper angles and thicknesses, all cross notchings cut, all holes drilled, and all necessary cutting about done before they are creosoted? Such constructions would not, presumably, give any trouble owing to the wet getting in at places where they are cut about or bored. I have not had time to see how much we could have benefited if we had had the knowledge that Mr. Wade has now put at our disposal in constructing our work in South Wales, but I shall take an early opportunity of working it out.

Mr. Gavey. Mr. J. Gavey, C.B.: Many of the remarks that I might otherwise have made have been anticipated by previous speakers, but there is one point to which I should like to allude which may be interesting to the present audience. When the tests were made whereby the Post Office determined the value of the factor of rupture, we had some old poles dug up that had been in the ground fourteen years, in order that we might ascertain whether, during that interval, they had lost any of their strength. We were much pleased to find that the value of K in these poles that had been in use for fourteen years differed but slightly from the corresponding value in the new poles that we tested. Some reference has been made this evening to creosoting. I need not say there is creosoting *and* creosoting. If we want poles to be thoroughly

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Mr. Gavey.

durable and to justify the estimates of life suggested by certain previous speakers, the creosoting must be thoroughly well done under the best conditions. The poles must be very dry when they are put into the tanks, and the whole of the terms of the best specification must be closely adhered to, otherwise the result will be disappointing. In the course of my experience I have had to renew so-called creosoted poles which had only been in the ground eight or ten years. They, I need not say, had not been thoroughly well creosoted, otherwise they would have lasted much longer. Mr. Trotter referred to the question as to whether in the olden days, to which my memory carries me back, creosoting was as well done as it is now. Probably the process may not have been so scientifically carried out, but I think there was a countervailing advantage; that is to say, in those days nothing was extracted from the creosote. The creosote with all its antiseptic ingredients was injected into the timber, but in later years it has been the practice in many cases to extract many valuable products from the creosote itself. I must confess that a few years ago I rather wondered whether the preservative qualities of the creosote would be deteriorated by the extraction of some of the antiseptic components of the material. I have not lately had any reason to think that that fear was well founded, and I have every reason to believe that thorough creosoting at the present day is as effective as it was in the olden days. Much has been said about the ground-hold of A poles. That, I think, is a question the importance of which cannot be over-exaggerated. I have no doubt whatever that the failure of a well-erected A pole line will not arise either from the sliding of the two portions of the joint one over the other, or by the buckling or failure of the poles. If an A pole line goes, it will go through the failure of the ground to hold it. Mr. Wade's paper has illustrated the difficulties experienced in getting a thoroughly suitable foundation to test the poles effectively, and I do not think it is possible, in any ordinary line construction, to get anything like such a thoroughly sound holding in the ground in ordinary soil as will admit of an A pole being actually fractured by any stresses that come upon it. With regard to the question of the decay of creosoted poles, decay takes place in all kinds of places. We all know that creosote does not penetrate the heart wood of the pole, and occasionally it is the heart that goes. On the other hand, I have seen creosoted poles in which the external shell looked as sound as ever it was, but the pole commenced to rot just inside a thin shell that might only be half or three-quarters of an inch in thickness. One cannot predict the locality of the decay in creosoted poles as one can in an ordinary untreated pole, which, as is well known, always goes at the ground line. Much has been said about the erection of single poles *versus* A poles, and an idea appears to exist that all the main telegraph lines throughout the country are single pole lines. They are single pole lines to this extent, that as a rule there is, in the majority of them, a single pole standing up, but we do not depend on the strength of that single pole alone. I think any one driving along our country roads

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Mr. Gavey. will find that all our main lines are either so well stayed or strutted throughout that they are equivalent to A pole lines. For telegraph and telephone purposes, unless it is desired to erect a very large and heavy line, it is in very many cases a matter of convenience, where there is room for strutting and staying, to erect single pole lines, and to obtain the necessary strength by the addition of struts and stays. The value of that arrangement for telegraph and telephone purposes has been dwelt upon by Mr. Gill. I have only one other point to refer to, and that is the rupture of an A or an H pole by the buckling of the member under compression. I think that, wherever such a structure is exposed to destructive stresses, the structure will always go by the buckling of the inner pole. I have noticed myself on many occasions, where H poles have been erected in places where the stress was very heavy, that the member under compression was always the first to show signs of distress, and I think, considering the distribution of the mechanical stresses, it will be obvious that it must be so. We have a structure which consists of a very thin girder of very great depth and very little breadth, and when destructive stresses are put on that girder I think it must fail by twisting. The whole strength of the timber can never be utilised so long as the timber is built up in the form of a very narrow, deep girder with great transverse but little longitudinal stiffness.

Mr. Watts. Mr. A. WATTS (*communicated*): The main feature of the tests described is the establishment of the fact that an A pole has at right angles to the route about four and a half times the strength of a single pole of the same size. My opinion is that, although this additional strength may be obtained in the structure, the holding power of the ground is not increased in a corresponding ratio. This opinion is strengthened by the statement of the Engineer-in-Chief to the Post Office to the effect that he has never seen a single pole broken, the ground always giving way first. Such being the case, there is no object in increasing the strength of the structure without increasing that of the anchorage.

The following is a suggestion for an improvement in this direction without materially increasing the cost. A guy anchor of the requisite dimensions is inserted in the ground in the usual manner in such a way that each rod will project from the bottom of the pole hole in the direction to be taken by the corresponding member of the A structure, to which both of the rods should be securely fastened (Fig. C).

The holding power of the type of anchor shown varies, of course, with the nature of the ground, and can be approximately calculated for sandy soil by a formula given by Professor R. C. Carpenter, of Cornell University, U.S.A., based on a series of actual tests; he gives it as follows:—

$$R = 100\,D\,H^2;$$

when— R = resistance in lbs.,
H = depth of anchor in feet,
D = diameter of helix.

The resistance of clay ground will probably be 20 per cent. more.

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Some experiments were carried out by Mr. Magnall, District Engineer, National Telephone Company, Manchester, in June, 1906, and results were obtained lower than would be given by the above formula, probably due to the different methods employed in making the test, and I would suggest as safe practice that the constant of 100 Mr. Watts.

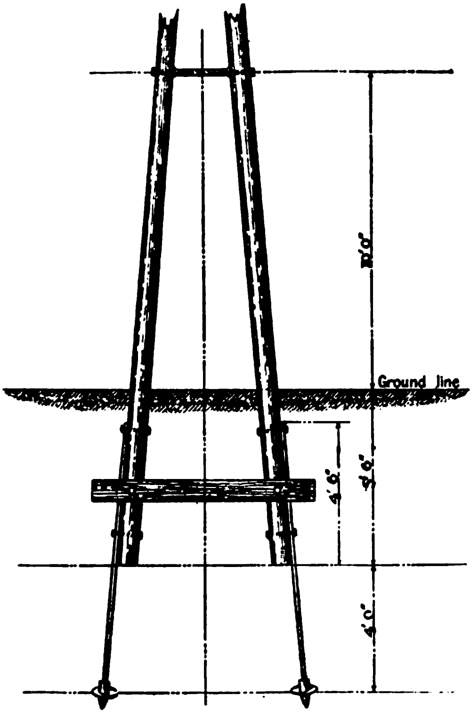

Fig. C.

be reduced to 75. If a calculation be made on this basis, it will be found that sufficient holding power can be added to an A structure to correspond with its increased strength over a single pole. An anchor of the type shown bores into the ground in the same way as a wood screw into timber, and consequently is very easily and cheaply fixed.

Mr. J. H. M. Wakefield (*communicated*): Mr. Trotter in his remarks stated that, generally speaking, power undertakers commenced where the telephone and telegraph undertakers left off, but in the absence of details as to the definite stresses put on the poles by the power wires it is difficult to make a comparison. In many cases telegraph and telephone poles, in my opinion, are subjected to quite as much stress, if not more, as power-circuit poles. The wind pressure in Mr. Wakefield.

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Mr. Wakefield.

the case quoted by Major O'Meara, viz., 64 wires on single poles, would be, for a 60 yards span of 200 lbs. copper wire (11½ S.W.G.), about half a ton. If the wires were pulled up to the usual tension, say 66 lbs. at 60° F., the static stress would approach 2 tons. It must not be forgotten that telegraph and telephone poles are much higher than power-circuit poles as a rule, and therefore the moment of pressure is considerably increased. If Mr. Wade has any details of the stresses actually applied to the lines shown in his photographs, perhaps he can give figures in his reply in order that a comparison may be made with the case quoted.

With reference to Figs. 19 and 20 of the paper, stays in the direction of the stresses, say at every sixth pole, would prevent the bending shown to a large extent. Stays, in fact, whether longitudinal or transverse, are the salvation of a line.

Mr. Monckton.

Mr. C. C. F. MONCKTON (*communicated*): With reference to wooden poles being unsuited for certain climates, it is my experience that it is not climate but acids due to tropical vegetation that usually play havoc with wooden poles. The poles usually rot where they enter the ground. In the West Indies, in towns where the acids are not present to such a great extent, yellow pine has lasted for five or more years. Attempts were made to use cast-iron sockets, but the poles were thinned where they entered the sockets and had the effect of making the poles still weaker at their weakest place. Another method has been to sheet the parts with lead from a foot below the surface to a foot above. This has been found very effective if well done, but it has been given up in most places on the score of expense. In Jamaica it is the common practice to bolt pine posts to hard wood cashaw butts. The objection to this practice is the same as to the cast-iron base: the posts are usually greatly weakened at the point of junction. In Trinidad local woods are to a certain extent used. Balata has been tried, but often the gum has been extracted, and they split with the sun in consequence. I have inspected moira poles placed in dense tropical vegetation ten years previously which did not show a trace of decay. On the other hand, where young, sappy moira has been used, the poles rot in less than a year. Probably British Guiana has a fine field in exporting hard woods on account of river facilities, and walaba from there has of late years been largely used both in Barbados and Trinidad for heavy work.

Mr. Wade.

Mr. C. WADE: In reply to the discussion on the paper I had the pleasure of reading before the Institution of Electrical Engineers, I should like to deal with the points raised in their order.

As Professor Goodman remarks, I think it is quite correct to leave out of the question the weight of the wires to a span (in calculating the size of poles in erecting a line) as these are balanced all along the line. I have tried to show, and Mr. Trotter also points out, that their weight introduces a very small compressive stress on the poles, and I have therefore only dealt with the wind pressure on the wires.

I also think that as far as possible every case should be treated on

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Mr. Wade.

its merits as regards wind pressure according to whether it is in an *exposed position* or not, before the size of pole to be used is decided on, or the regulations with which it has to comply.

The foundations of poles are also very important, and if we grant that a pole, especially an A pole, will pull out of the ground before it breaks, it will be necessary to put in a better foundation. The experiments show that such a foundation requires to be of enormous strength to allow of the pole breaking before itself giving way. (See reply to Mr. Watts.)

The question of staying poles I have not dealt with, as it is a very complicated one and resolves itself into a question of the comparative cost of different forms of poles, which Mr. Gill has mentioned, and with which I shall deal later. I quite agree with Professor Goodman that the method of constructing H poles can be improved, but this is more a question for engineers than myself. It might be possible to stay the compression pole in an A pole to prevent buckling if the cost does not outweigh the advantage.

Major O'Meara has, I think, misunderstood the object and results of my tests. I was perfectly aware of the existence of the Post Office's valuable tests and the book dealing with the same, as also were the persons I first consulted with, in regard to the strength of timber. But I think it does not deal with any point I have raised, and I think, as Mr. Trotter has remarked, telegraph work ends where high-tension transmission begins.

I regret if there is a similarity between the engravings in my paper and those in the Post Office book, but would like it to be quite understood that these were made without reference to that work, being mostly diagrams of my actual tests, and photographs of the same; the others were compiled by me from past experience of the usual practice of the engineers I had come in contact with, and on looking through the Post Office book again I fail to see any drawings resembling mine. The Post Office tests dealt extensively with the strength of single poles, but I believe I am correct in stating that no one had experimented with double poles before my tests were made. Of course I am aware other extensive and valuable tests have been made with different kinds of timber for various purposes, and that there were some tests on a large scale carried out by the Government of Western Australia, etc.

As to the life of a creosoted pole, my estimate was perhaps too high in putting it at fifty years, although I have come across cases of poles having lasted this time. And I should say modern means of creosoting are as good, if not better, than those employed thirty years ago. Some remarks have been added by Major O'Meara, which I think afford very good testimony as to the value of creosoting poles. These are very interesting inasmuch as the figures are more favourable than the previous ones of the Post Office, and certainly show that some poles are still in use after thirty-seven years.

There is also a new German process extant (which I am watching)

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Mr. Wade. which may show better results. This has not yet withstood the test of time, but is probably the one referred to in regard to creosoting in that country.

In reference to Major O'Meara's figures, and as mentioned by Mr. Wakefield, at a 60-yard span 64 wires of $\frac{1}{12}$ S.W.G. would about equal $\frac{1}{2}$ ton or 1133 lbs. in wind pressure taken as 17 lbs. to the square foot. I do not see how the wires being pulled up to a tension of 66 lbs., as suggested by Mr. Wakefield, affects my argument, as any extra tightening up in the direction of the line would not be felt by any individual pole, but be compensated all along the line, so that stays are unnecessary.

Mr. Trotter thinks I have given him undue credit for suggesting these tests. I must confess, however, that an interest in the matter has greatly influenced me in making them, and I am indebted to Mr. Trotter for the suggestion on behalf of the Board of Trade that such figures would be of value. The poles tested were red fir, which I regret I omitted to state. We must all thank Mr. Trotter for the concessions he has already induced the Board of Trade to make, and must bear in mind that in some cases timber may fail at a lower load than is expected. With the question of creosoting timber I have dealt elsewhere.

Mr. Gill must not forget that when I said a single pole was useless, I was speaking of high-tension work which is under much more stringent rules and requires a higher factor of safety than telephone work; I did not mean that because a single pole was too weak to comply with regulations and to carry high-tension mains it was useless for lighter work.

On the question of staying, I cannot reply fully to Mr. Gill, as I considered it too complex a question to enter into. I have no doubt if a ludicrously small pole were put up and stayed at all points, so that the load practically resolved itself into a compression, it would carry a large number of wires. But it then becomes a question of cost, and the following figures will show the comparative cost of single and A poles apart from staying. The question of foundations I have before mentioned. I did not mean to convey that the St. Etienne line I named had a factor of safety of 10, as I do not know if it had, but it was no doubt put up in conformity with the practice in its own country and stood.

In regard to the letter T in the Appendix, Table III., which Mr. Gill refers to, Professor Goodman, no doubt, meant that in the tables he has prepared for me, we are taking this as a constant of 24 ins. In the actual tests it varied slightly from 23 ins. to 29 ins., for which allowance has been made.

I do not know how Mr. Gill arrives at his figures of comparative cost of single and A poles, but I think for high-tension work A poles are far cheaper and more satisfactory. I am surprised to hear Mr. Gill say a single pole is stiffer in the line of the wires than an A pole, unless he means that it was stayed in that direction. As I take

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Mr. Wade.

High-tension Work. Board of Trade Rules.

Factor of safety, 10. Clearance, 25 ft.
Wind pressure, 30 lbs. per square foot. In ground, 5 ft.
Total length of pole, 32 ft. From wires to top of pole, 2 ft.
Diameter of poles taken at 5 ft. from butt end.

Span 40 yds.: Safe Load across the Line in Pounds.	Wind on Equivalent Wires to Load.	A Poles.	Relative Cost.	Nearest Single Pole to carry same Load.		Relative Cost.	Load Single Poles of same Diameter as A Poles will carry.	
	At 30 lbs. per sq. ft.	Diam. in ins.		Diam. in ins.	Load.		Diam. in ins.	Load.
231 lbs.	About 4 S.W.G. 1/0	7	0·236	11½ 12	209 lbs. 253 „	0·224 0·273	7 7	None.
407 „	„ 6 „	8	0·254	13½	415 „	0·545	8	9 lbs.
640 „	„ 10 „	9	0·333	15	620 „	1·00	9	51 „
925 „	„ 14 „	10	0·363	Too large to be obtained.			10	106 „
1,270 „	„ 18 „	11	0·515				11	168 „
1,710 „	„ 26 „	12	0·666				12	253 „
Same as above, but with factor of safety 8 and wind pressure 17 lbs. to square foot								
	At 17 lbs. per sq. ft.							
401 „	„ 11 „	7	0·236	11½	384 „	0·224	7	48 „
631 „	„ 17 „	8	0·254	13	588 „	0·510	8	95 „
930 „	„ 25 „	9	0·333	15	942 „	0·100	9	155 „
1,312 „	„ 36 „	10	0·363	Too large to be obtained.			10	235 „
1,764 „	„ 48 „	11	0·515				11	328 „
2,319 „	„ 63 „	12	0·666				12	448 „

it a single pole 12 ins. diameter at 5 ft. from butt required to carry the same load as a 7-in. A pole would have very considerably more deflection under load than the A pole and would cost about the same. It is in the larger loads and poles required to carry same that the advantage of an A pole is more apparent.

As Mr. Gill says, there is also the question of the single pole disturbing less ground in erection than the A pole, and so getting a more solid foundation; against which the A pole has more leverage, and is assisted in holding in its foundation by its cross-brace block, and can be anchored as suggested by Mr. Watts. Also, as Mr. C. H. K. Chamen remarked, it is very necessary to avoid the extra expense, trouble, and ground occupied by stays on single poles.

Mr. C. H. K. Chamen mentions the initial sag on the poles in the tests, and I think Professor Goodman and we all agree that this caused our results to be lower than they should have been.

In regard to the lightness of poles, this to a great extent was the reason why I undertook the tests, in order to see whether the then

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Mr. Wade. existing ideas of size are correct, and, if not, whether the first cost could not be reduced, with the object of increasing the amount of overhead lines used.

I think I have shown that A poles may safely be used of about three-quarters the size of those commonly employed which will reduce the initial cost to about one-half. In addition, such poles are, of course, lighter and easier to handle. But whether two light A poles could be used with advantage instead of one seems doubtful.

Square poles are a fad, and are not nearly as strong as when in their natural state.

Mr. Greene has been a most valuable and interested helper at the tests, and it was thanks to him in a large measure that the results, of whatever value they were, have been arrived at.

In regard to the breaking-point of poles, Professor Goodman seems to think that the position in which this occurred largely depended on the method of testing. Being about 5 or 6 ft. above the supports, it is, he thinks, due to the fact that on account of the weight of the pole the stress is greatest at the middle section, and would therefore tend to break it in the middle, but owing to the lateral pull by means of the chain they tended to break at the housing; hence, when we have both the weight of the pole and the pull of the chain acting at the same time, the section at which the fracture occurs is naturally between the two, and if one goes carefully into the mathematical treatment of it, as Professor Goodman has done, one finds that the pole should break in the neighbourhood of 6 or 7 ft. above the ground, as it did.

The question of way-leaves seems very important, and is a great check to proposed lines. Cannot it be overcome, if necessary, by powers obtained from Parliament to prevent undue obstruction on the part of landowners, as is done in Italy and other countries?

In reply to Mr. W. A. Chamen: Assuming that the S. Wales lines were put up on a 40-yard span, A poles of 7 to 7½ diam. at 5 ft. from butt or a single pole of 12 ins. should have carried the line, which shows, according to my figures, that the poles were much too heavy.

Mr. Chamen also raises a very important point, viz., the standardisation of poles. I hope, in view of the figures I am now publishing, that a uniform design will be adopted, and that it will be possible to make a hundred as easily as one, and to do all the preparing (as I much prefer) before they leave the pole yard, but I do not think that telegraph poles can be prepared in a copying lathe. Whether a pole fails either in breaking or decay depends on circumstances which I deal with elsewhere, and has also been dealt with by others. It would seem that an A pole takes as little, if not less, room than a stayed single pole, and is, therefore, probably less costly in way-leaves.

The life of creosoted timber has been fully dealt with by gentlemen in a far better position to judge than myself, but I think that a properly creosoted pole will outlive (and at a far less cost) any other similar structure erected. It may break at the ground or top, depending

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where rot is let in or the nature of the ground it is in or the degree of imperviousness it has attained in creosoting. Mr. Wade.

Mr. Gavey dealt with the point of failure of creosoted timber and plain timber. As far as I know, the failure of creosoted timber is due principally to rot internally, set up by entrance through an opening usually caused by cutting through the creosoted surface, which points to the advantage of all cutting being done before creosoting. As Mr. Gavey said, an unprepared pole always goes at the ground line 'twixt wind and water, but a creosoted pole will often be found perfect externally with a hollow interior caused by dry rot let in somewhere. I am glad to see Mr. Gavey thinks the value of it is not lessened appreciably after the poles have been used some time.

I think Mr. A. Watts' suggestion as to the anchorage of the legs of an A pole is the best I have seen, and in order to render of use the results I have obtained as to the strength of A poles, it is necessary to improve the method of holding them in the ground, if we grant that the structure will pull out of the ground before it breaks. The results given by Professor Carpenter and Mr. Magnall are very interesting, and will, no doubt, be of value in using these anchors, but in his formula he does not say if the diameter of the helix is taken in feet or inches. As Mr. Watts mentions, we have shown that (apart from its foundation) an A pole is stronger than a single one, and a very large and expensive single pole is required to carry a high-tension load, but the extra strength above ground is of very little use unless we increase the holding power below the surface.

Mr. Wakefield seems to have missed the points of the case, which is that we are dealing with the wind pressure on the wires only, and not their weight. The weight is compensated all along the line and taken at the end by terminal poles.

The elasticity, as shown in Figs. 19 and 20, was put in purposely to show that the poles would bend sufficiently (in case of a break in the wires) to take up the load without breaking the poles themselves or do any serious damage, and not to assist people in devising stays to avoid this deflection. In regard to the stresses on the actual lines shown, figures will be more readily obtained from those who erected the lines than myself.

I have an idea they carried six wires about $\frac{1}{2}$ diam. or 1/7·0 S.W.G., which, with a presumed span of 40 yards, is a wind pressure per wire (taken at 30 lbs. per square foot) of 100 lbs. each, or a total 600 lbs. (nearly double that taken at 17 lbs. per square foot as usually taken for telephone work); and if we take the wind pressure as 600 lbs. for the sake of argument, granting a clearance of, say, 25 ft., we shall require a single pole of 14 ins. diam. at 5 ft. from the butt or an A pole with each leg 9 ins. (For comparisons of cost see reply to Mr. Gill.)

If each pole has to be strong enough to remain perpendicular *in case of a break*, we should require enormous poles and also stays, and this is why we consider the flexibility of wooden poles of some value.

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Mr. Wade.

The diameters of poles in Figs. 23 and 24 can now be obtained from Table III. by means of the reference letters.

The castings and bands at the top of an A pole commend themselves to some users, and must be taken on their merits, but I think, with Mr. Green, that the bands are of most use, and the chief objection to them is, they are difficult to fit to the poles or make in a quantity to pattern on account of the poles varying in size.

Mr. Monckton suggests it is the acids due to tropical climes which affect the timber. My impression was that insects like the white ant were to blame. I have very little experience in this matter, but have been told that creosoted red wood will stand a certain time, until the heat in the tropics draws out and weakens the preservative to such an extent that the timber rots or is attacked by insects.

The thing I had feared was destructive insects like the white ant, and think in some parts if a preservative will exclude them, the timber will remain good as easily there as in our climate.

The Chairman.

The CHAIRMAN: Mr. Wade has given us a paper which, in this particular line, will be one of the classics which we shall be glad to turn back to afterwards. We have to thank him most heartily, not only for the able paper that he has given us, but also for the interesting way in which he presented it.

The resolution of thanks was carried with acclamation.

The meeting adjourned at 9.48 p.m.

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BIRMINGHAM LOCAL SECTION.

RECENT IMPROVEMENTS IN ELECTRIC LIGHTING.

Abstract of Discussion introduced by

A. H. BATE, Associate Member.

(*January* 16, 1907.)

The Chairman, Mr. R. A. Chattock, called on Mr. Bate to open the discussion.

Although the incandescent electric lamp with a carbon filament has been on the market as a commercial article for more than twenty-five years, it remains to-day very much as it was in the year 1884. Except for the introduction of the 200-volt lamp the improvements that have been made in detail affect the life of the filament and cost of production. The arc lamp also, except for the invention of the enclosed lamp and the simplification of the feeding mechanism, has not been radically altered, and until about five years ago these two lamps were the only ones available. In late years, however, several new devices have been produced, all of which aim at reducing the current consumption, and it is in the direction of high-efficiency lamps that we must look for reduction in the total cost of electric lighting.

No doubt in the near future we shall be able to choose between several kinds of metal filament lamps, but at present the only lamp which is being used on a large scale is the tantalum. These lamps are not at present made for pressures above 130 volts. When one remembers that the hot resistance of an 110-volt lamp must be rather over 300 ohms, and that this requires something like 24 ins. of wire 1·4 mils. diameter, that is to say, about 43 S.W.G., it is not surprising that some difficulty has been found in exceeding a voltage of 130.

At the present time there are only two sizes of wire being used in the manufacture of these lamps, one size being suitable for the ordinary lamp giving 23 candle-power on 110 volts, and the other for the "Sun" lamps giving 45 candle-power at the same pressure. More or less wire is wound on the frame according to the voltage for which the lamp is

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intended, and the candle-power is proportional to the volts, at the same efficiency.

Owing to the way in which the filaments are wound there is a comparatively small candle-power directly downward in the direction of the axis of the lamp. To provide a more uniform distribution of the light the end of the bulb is frosted. At first sight one would expect this to reduce the illumination in that direction, but experience has shown it has the effect of increasing it nearly three-fold. In looking at the bottom of a lamp one is looking on the end of a cylinder formed by the tantalum wires. As the obscure end of the lamp is much nearer to these wires it subtends the wires at a larger angle, and each part of the frosted globe receives a larger amount of light than would reach the eye directly downward.

The life of different individual tantalum lamps varies considerably. With metal filament lamps one has not the advantage that exists with the carbon lamp of "flashing," a treatment by which the weak portions of the filament are automatically strengthened. Notwithstanding this, an extended experience with the tantalum shows that at normal voltage, and if the lamps are not overrun, they have an average efficient life of 600 to 700 hours. By efficient life I mean up to the time the candle-power drops 20 per cent. During the first forty or fifty hours of the life the resistance falls about 3 per cent. and then remains practically constant throughout its life. While the resistance is falling the candle-power naturally increases, and then as the globe is slowly blackened, falls off again till in about 700 hours it has fallen 20 per cent. below the marked figure. By running a lamp something like 10 volts below its marked figure an efficiency of 2·2 watts per candle is obtained instead of the usual 1·7 watts per candle, and the efficient life is then increased to about 1,200 to 1,400 hours.

If energy can be obtained at 1d. per B.T.U., no particular advantage can be claimed for tantalum as compared with carbon filament lamps. The high efficiency of the former is just balanced by its greater initial cost (2s. 9d. as compared with 6d. or 8d.). But with higher rates per B.T.U. the tantalum lamp gives a considerably decreased cost, even reducing the current bill to one half. I have made this comparison on the basis of the cost per 1,000 candle-power-hours. Taking the cost per lamp the advantage of the tantalum is not so marked as one usually replaces a 16 candle-power carbon filament lamp with a 23 candle-power tantalum, and the advantage is shared between decreased current bill and increased illumination.

One interesting feature of these lamps may be mentioned. In many cases it is possible to make the broken ends of the filament touch by shaking the lamp, and if this is done while the pressure is applied to the terminals, the broken ends of the wire will weld together, and if too great a length of the filament is not cut out of circuit the lamp starts again with a new lease of life.

Mr. Forster. Mr. A. LINDSAY FORSTER: I made out for my own use some months ago the following table, showing the complete costs of lighting with

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different forms of lamps, some of which are based on my own personal experience, and others on published data:— Mr. Forster.

COSTS OF RUNNING VARIOUS HIGH POWER LAMPS FOR 1,000 HOURS ON 220 VOLTS DIRECT-CURRENT INSTALLATION.

Flame Arc (9-amp. 17-hour, with chemical carbons).

	£	s.	d.	
2,000 units @ 1½d.	12	10	0	
Carbons	4	10	0	
260 trims (wages)	2	3	4	
Repairs	2	8	0	
Four lamps ...	£21	11	4	(per lamp £5 8s.)

Flame Arc (7-amp. 40-hour (magazine) with chemical carbons).

	£	s.	d.	
1,650 units @ 1½d.	10	6	3	
120 trims (wages)	1	0	0	
Carbons	1	10	0	
Repairs	3	0	0	
Four lamps ...	£15	16	3	(per lamp £3 19s.)

Single Enclosure Arc (5-amp. 120-hour).

	£	s.	d.	
1,100 units @ 1½d.	6	17	6	
Carbons	0	2	0	
24 trims	0	4	0	
Repairs	1	0	0	
Two lamps ...	£8	3	6	(per lamp £4 1s. 9d.)

Mercury Vapour (680-c.p. 3·5-amp., 2 in series on 220 volts).

	£	s.	d.	
770 units @ 1½d....	4	16	3	
Renewals @ 1,500 hours ...	3	1	0	
Cleaning and repairs	0	15	0	
Two lamps ...	8	12	3	(per lamp £4 6s. 0d.)

If life of tubes is 800 hours ...£11 5s. 3d. (per lamp £5 12s. 8d.)

High-pressure gas, say 350 c.p., gas @ 1s. 9d. per 1,000 cub. ft. Cost, including mantles, attendance, bye-pass, etc., per 1,000 hours, £4 6s. 3d.

Mr. J. H. CRAIG: Taking the case of a big electric shop, say about 200 ft. long, the cost of current from the Birmingham Corporation Mr. Craig.

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Mr. Craig. mains, using enclosed arc lamps, would be 9s. per hour for lighting the shop.

With flame arc lamps, which give half as much more candle-power and work at an efficiency of 0·24 watt per mean hemispherical candle, the cost works out at 2s. 11d.

The Mercury vapour lamp is not so efficient as the flame arc lamp, as it takes nearly half a watt per candle-power owing to the better diffusion. The illuminating effect is better than with arc lamps, illuminations of from 1 to 2 candles per square foot, with lamps placed at heights of 11 ft. to 50 ft. giving satisfactory results. Assuming that the roof of the shop is low enough, the same illumination as by enclosed arc lamps can be obtained for 4s. 4d. per hour. These figures do not include capital charges, or renewals of carbons or lamps. The life of the mercury vapour lamp may be taken as 1,000 hours on an average.

Dr. Morris. Dr. D. K. MORRIS: The resistance of a carbon filament decreases 60 per cent. with an increase of temperature, but the resistance of a tantalum filament increases about six times when heated. The low, cold resistance might make it impossible to use the magnetic circuit-breaker, which would be pulled out when the lamps are switched on.

The short life of the tantalum lamp on alternating-current circuits may be due to the wave-form. Mr. J. T. Morris,* has given curves of the instantaneous values of candle-power and amperes, which show that the candle-power varies 20 per cent., thus even with a normal voltage the filament may be momentarily overrun.

Dr. Sumpner. Dr. W. E. SUMPNER: The diffusion of light is a matter that does *not* affect our judgment of the different kinds of glow lamps or arc lamps, but it does affect our judgment of the relative cost of arc lamps and glow lamps. In an ordinary room the illumination is doubled owing to diffusion, and with whitewashed walls and ceiling, the light might be increased five times. The measurement of the candle-power of a mercury lamp is by no means easy. If we have a diffusing reflector, reflecting 80 per cent., and a mirror reflecting 80 per cent., and measure the candle-power normal to the surface, then the diffusing reflector sends off twice as much light as the mirror does, although the total amount of light reflected is the same in both cases. I believe the working efficiency of the mercury vapour lamp is much better than photometric figures show.

Mr. Kemp, Mr. Tweedy, and Mr. Fennell also joined in the discussion.

Mr. Bate. Mr. BATE (*in reply*): If, as Dr. Morris suggested, the peculiar behaviour of tantalum lamps with alternating current has something to do with the wave-form connected with the rapid change of resistance, surely the change of periodicity from 50 to 100 $\sim$ per second will have a very much greater influence on the lamps, and as far as we know the lamps burn as well on one periodicity as on the other. As to diffusion of light, a very good example of the way in which it is appreciated by the general public is to be seen in the popularity of the large bulb high

* *Electrician*, vol. 58, 1906, p. 318.

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efficiency ordinary carbon incandescent lamp, the use of which has been one of the most striking features of electric lighting during the last two or three years. As to the tantalum lamp, the greath length of the wire that has to be accommodated in the bulb, though a disadvantage in one way, becomes an advantage in another way because it provides an area of illuminating surface very many times larger than the filament of an ordinary carbon lamp. Another point is that owing to the great increase of resistance with the temperature the tantalum lamp bears a small over-pressure better than it would if it retained its resistance constant. Mr. Bate.

On the proposition of the Chairman, a vote of thanks was passed to Mr. Bate, and the meeting terminated.

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BIRMINGHAM LOCAL SECTION.

CENTRAL STATION SUPPLY ECONOMICS; THEIR STUDY, AND WHAT IT PROMISES IN THE WAY OF CHEAPER SUPPLY.

By A. M. TAYLOR, Member.

(*Paper read February* 13, 1907.)

SUMMARY.

Definition of terms—Running charge for coal, wages, repairs, etc., analysed and separated from standing charges—Division of charges in combined lighting and traction stations analysed—Charge per unit to consumer unaffected by internal diversity factor of power load—Effect of combined diversity factor of the traction, power, and lighting loads in reducing standing charges—Ideal load needed to warrant the offering of ideal terms for current—Storage provides us with such an ideal load—Conclusions.

INTRODUCTION.

This paper does not pretend to be a complete statement of the subject of central station economics, the subject being really too large to be compressed into the limits of a short paper like the present one. Though I feel how inadequately I have been forced to treat the subject, it is hoped that discussion may be provoked on the part of central station engineers and others, and thereby doubtful points be cleared up and the common fund of knowledge added to.

DEFINITIONS.

Plant Load Factor.—The ratio of the average load on the generators, taken over the year, to their aggregate rated power (not overloaded; but including spares).

Station Load Factor.—The ratio of the average load on the station feeders, taken over the year, to the maximum observed load on the station.

Consumers' Load Factor.—The ratio of the average load (deduced from B.H.P. hours where motors are concerned) given out, or absorbed, by consumer's apparatus, to the maximum possible capable of being absorbed or given out.

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Internal Diversity Factor.—When applied to a motor load, this represents, at any instant, the number of times which the sum of all the maximum loads on consumers' premises exceeds that observed at the central station.

Unrealised Diversity Factor.—This is the amount by which the observed diversity factor falls short of what it should be in order to satisfy the equation: Consumers' load factor × diversity factor = station load factor.

RUNNING CHARGES AND FIXED CHARGES.

Every item of annual expense may be divided into three parts:—

1. A part termed the running charge, proportional in amount to the number of units generated.
2. A part independent of the number of units, but dependent on the maximum demand of the station.
3. A part dependent on the number of consumers.

Items 2 and 3 may, without great error, be classed together as standing charges.

I propose to consider these charges both in their relation to a lighting load, to an ordinary "interest-paying" motor load, to a traction load, and to a restricted hours load.

1. *Coal.*—In order to fix ideas and facilitate the investigation that follows, I have represented, in Fig. 1, the coal performances of a complete station, whose most economical (engine) load is 3,000 k.w. This station might consist of two 500 k.w. sets, three 1,000 k.w. sets, and a spare 1,000 k.w. set.

The curve (A B) represents the engine performance alone. It is really a steam performance at the engine stop-valve; but may be expressed on the diagram as a coal performance.

Boiler standby losses, steam range and auxiliary plant losses, looking at the station as a whole, bring the curve up to (A′ B′).

The curve (C D) similarly represents the steam consumption, for the engine only, expressed as lbs. of coal per unit generated; and the curve (C′ D′) represents the lbs. of coal per unit generated, including boiler standby, steam range and auxiliary plant losses, for the whole station.

The importance of the plant load factor upon the determination of the standing charges for coal is obvious; this item being only 1½ lbs. of coal per unit, for a 20 per cent. plant load factor, whereas it is 3 lbs. for a 10 per cent. load factor.

Knowing the average engine consumption on test at different loads, the plant load factor, and the total consumption per unit averaged over the year, as well as the boiler coal consumption under test when feeding the engine and the auxiliaries, we can construct the four curves of Fig. 1 and learn the relation of "running" and "standing" charges for coal. Obviously, the steam consumption accounted for by the

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engines, on the plant load factors frequently obtaining (such as 10 to 20 per cent.), leaves the unaccounted coal consumption as that chargeable to the standby losses of boilers and auxiliary plant.

Let us now investigate somewhat more carefully into the 4 lbs. of coal taken as the running charge in the above figure.

Assume the whole station to be working at its maximum economical load for the complete twenty-four hours, so that it should be possible to realise the guarantees of the makers for the evaporation of the boilers

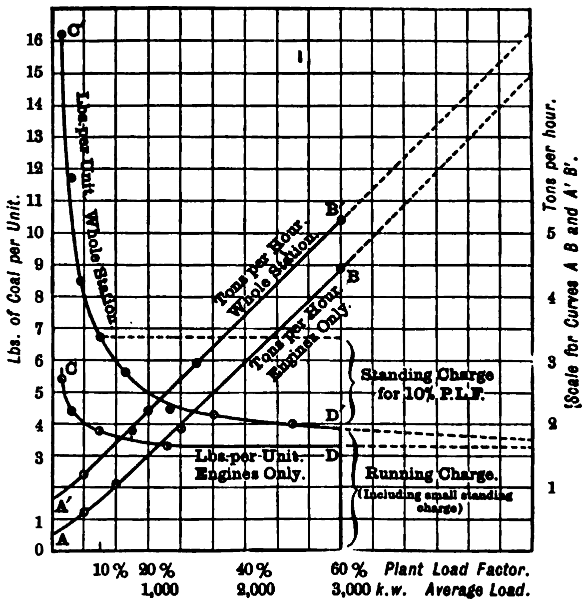

FIG. 1.—Coal Diagram for Station.

NOTE.—Maximum Boiler Evaporation taken at 7 lbs. per lb. of coal.
Total plant capacity (including spares) = 5,000 k.w.
For constructive details of curves see Table II. (in appendix to paper).

and the steam consumption of the engines, and to eliminate all standby losses in boilers, pipework, and auxiliaries, etc.

It has not, for some years past, been difficult to get a 300–500 k.w. set whose steam consumption (condensing) is less than 25 lbs. per k.w. on full load, employing superheated steam. Add to this, say, 15 per cent. (3·75 lbs.) for steam consumption for auxiliaries (also working under best conditions) including condensing plant, loss in steam ranges, traps, etc., and we have a total of 29 lbs. of steam per electrical unit for an easily-attained figure for the most economical load, maintained constant all through the twenty-four hours.

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It is also comparatively easy to get a boiler which, when worked under similar conditions, will evaporate 7 lbs. of water from feed at 210° F. to steam at 180 lbs., with 100° F. of superheat, for every lb. of slack (11,000 B.T.U.) costing, say, 7s. 6d. per ton (*i.e.*, 0·04d. per lb.). Hence, as a round figure, 4 lbs. of slack will evaporate the 29 lbs. of water required, at a cost of 0·16 pence per unit generated.

By substituting the corresponding values for the thermal value of the fuel at any particular place, and the cost of the fuel, the "running charge" for coal can at once be found for that town.

Owing to standby losses of all kinds, the actual coal consumption in stations of about 1,000 to 2,000 k.w. capacity may reach 8 to 12 lbs. per unit or even more; but the above figure of 4 lbs. per unit represents the whole of the additional coal consumption which would be incurred were we able to eliminate starting up and standby losses by throwing upon the station a load (such as a restricted hour load) which merely filled up the capacity of boilers and engines that were not running at their most economical load, though obliged to be kept under steam to deal with the evening "peak" or occasional fogs in the day time.

In a station where a combined lighting and traction supply is given, the number of boilers in commission all through the year would, in most cases, supply such a (restricted-hour) load, if of moderate dimensions, without further boilers being required to be started up; and in this case the above figure of 0·16 penny per unit would still hold for the charge debitable to that load.

In a non-traction station, however, it would be necessary for perhaps three months out of the 12, to keep in commission an extra boiler, to deal with the above class of load, unless very moderate in dimensions, and in such a case the above figure of 0·16d. per unit might be increased to, say, 0·20 penny per unit (generated).

We may summarise the above investigation by stating that:—The coal bill for a lighting station of about the capacity stated will be made up of two items, viz., a "running charge" of 0·16d. per unit (generated) plus a "standing charge" of, say, 0·24d. per unit (generated). Also that an "interest-paying" power load is debitable on account of coal with a running charge of 0·16d. plus a standby charge of, say, 0·12d. per unit (generated); the standby charge being halved on account of the doubled load factor.

Again, a traction load is debitable on account of coal with a running charge of 0·16d. plus a standby charge of 0·10d. per unit generated, the load factor in this case being taken at 2½ times that of the lighting.

Again, a restricted hour's load, provided it is not unduly developed, is debitable, on account of coal, with a running charge of 0·16d. *only*, where there is a traction load in the station as well; but if there is no traction load, it is debitable with 0·16d. plus, say, 0·04d. (25 per cent. of 0·16d.) as running and standby charges respectively per unit generated.

Collecting and tabulating the above results, we have, for coal charges per unit (generated):—

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Lighting.

Running charge = 0·16d.; standby charge = 0·24d.

*Powe*r.

„ „ = 0·16d.; „ „ = 0·12d.

Traction.

„ „ = 0·16d.; „ „ = 0·10d.

Average Combined Charge.

(For equal number of units, for all three classes of load.)

Running charge = 0·16d.; standby charge = 0·15d.

Combined charge = 0·31d.

Add 25 per cent. to all figures to bring them from per unit generated to per unit sold. It will be understood that the above figures refer to stations comparatively small in size, and that, with large stations employing units of 1,000 k.w. and upwards, they would be very considerably bettered.

For example, with the largest and most up-to-date sets, a steam consumption of 18 lbs. per k.w.-hour is attainable, and a boiler performance of 7½ lbs. of water evaporated per lb. of slack (11,000 B.T.U.), resulting in a coal consumption of not more than 2¾ lbs. of slack per k.w. hour, including a fair allowance for steam for auxiliaries and for losses in piping. The cost of 2¾ lbs. of slack at 0·04d. per lb. is 0·11d. per unit generated. The *total* cost, for coal, at Glasgow, for the traction load, including standby losses, does not exceed this. The object of the present paper, however, is to consider what may be done in the direction of cheapening power from the great majority of stations, and as we find them; and not to consider possibilities with ideal stations.

2. *Water and Petty Stores.*—It will be fairly safe to allow 0·02d. and 0·04d. per unit sold, for running and standing charges respectively for a lighting load; and 0·02d. and 0·02d. for a motor load, or a traction load; and 0·02d. alone for a restricted-hour load.

3. *Wages.*—It is, I believe, a common practice to allocate *half* the cost of wages to running and half to standing charges, and this has perhaps some justification in the fact that it is exceedingly difficult to frame any hard and fast rule by which to determine the proportion between them. It would, however, appear to be distinctly unfair to allocate to either a traction, lighting, or power load such a large charge for the running cost as the above proposition would give.

Consider a station with a combined maximum demand, for light and power of, say, 2,000 k.w., of which 1,000 k.w. are debitable to each class of load. In most stations such a condition postulates a power load development pretty far into the future, and hence the deductions that follow are financially safe.

Let the ordinate (C D) in Fig. 2 represent the total amount spent annually in wages on the combined scheme, and let (AB) be that which

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it is estimated would be required for wages on the lighting load alone; *i.e.*, assuming that the power load did not exist.

Join (C A) and produce through (A) till it cuts the scale of ordinates at £2,000 per annum. Draw a line horizontally through this point, as shown. Then, the total standing charges are represented by (L + P) and are equal to, say, £2,000 per annum.

Hence the standing charge per kilowatt (of station maximum demand) is £1 per annum. We thus obtain the curve (Q), which gives us the standing charge per kilowatt for different combined maximum demands of the same station.

The running charges for light and power are (L′) and (P′) respectively.

If we assume a power load factor of 25 per cent. and a lighting load factor of 12½ per cent., the combined load factor will be 18¾ per cent.

In Fig. 3 the standing charge of £1 per kilowatt per annum is plotted with the charge per unit necessary to give this return, for different load factors, or hours of use per day, determined in the usual manner.

Superposed on this curve is plotted the running cost charge per unit, obtained by taking the sum of the running costs (P′ + L′), amounting to £500 or $\left(\frac{500}{2000}=\right)$ 5s. per kilowatt per annum. Now 1 k.w. per annum at 12½ per cent. L.F. = 1095 units, and at 25 per cent. L.F. = 2190 units, and at 18¾ per cent. L.F. = 1635 units.

Hence *average* cost per unit $= \frac{60\cdot0 \text{ pence}}{1635 \text{ units}} = 0\cdot0367$d. per unit.

And cost per unit at 12½ per cent. L.F. $= \frac{60\cdot0 \text{ pence}}{1095 \text{ units}} = 0\cdot0548$d. per unit.

And cost per unit at 25 per cent. L.F. $= \frac{60\cdot0 \text{ pence}}{2190 \text{ units}} = 0\cdot0274$d. per unit.

We may, without material error, call the average figure a constant charge, viz., 0·0367d. per unit.; which again we may call roughly 0·04d. per unit.

Next, consider the case (Figs. 4 and 5) of a combined lighting, power, and traction load, each of a maximum demand of 1,000 k.w.

Taking load factors of 12½, 25, and 30 per cent. respectively, and estimating the annual charges for wages, for a combined lighting and power scheme without traction (from the known expenses of *one with* traction), and for a lighting scheme alone, we find a combined standing charge per kilowatt of 13s. 4d. per annum (Fig. 4). From this, the curve shown in Fig. 5 is readily deduced, and to this again is added the average running cost (0·03d.) per unit, obtained by dividing the combined running charge of 5s. per kilowatt per annum by the number of units (1,972) generated on a 22½ per cent. load factor, *i.e.*, the average of the load factors of the three classes of load. The curve so obtained gives for the values taken an average combined charge of approximately 0·11d. per unit generated; but as 0·15d. per unit sold is perhaps

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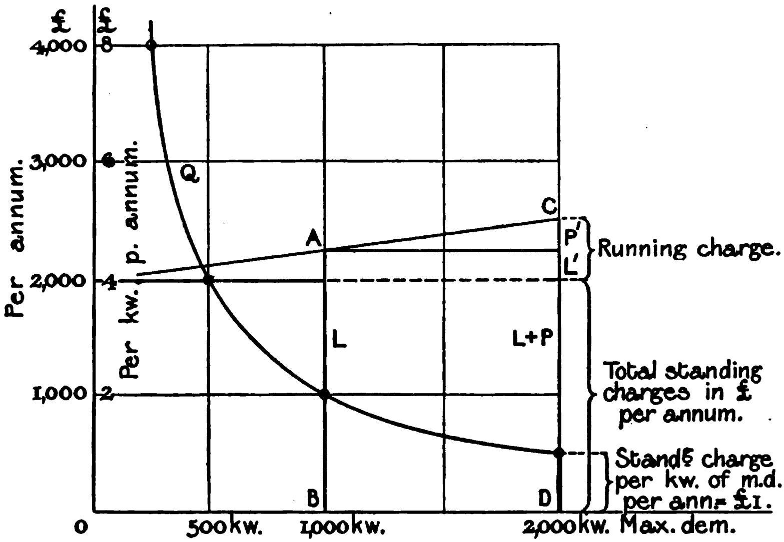

FIG. 2.—Wages Diagram.

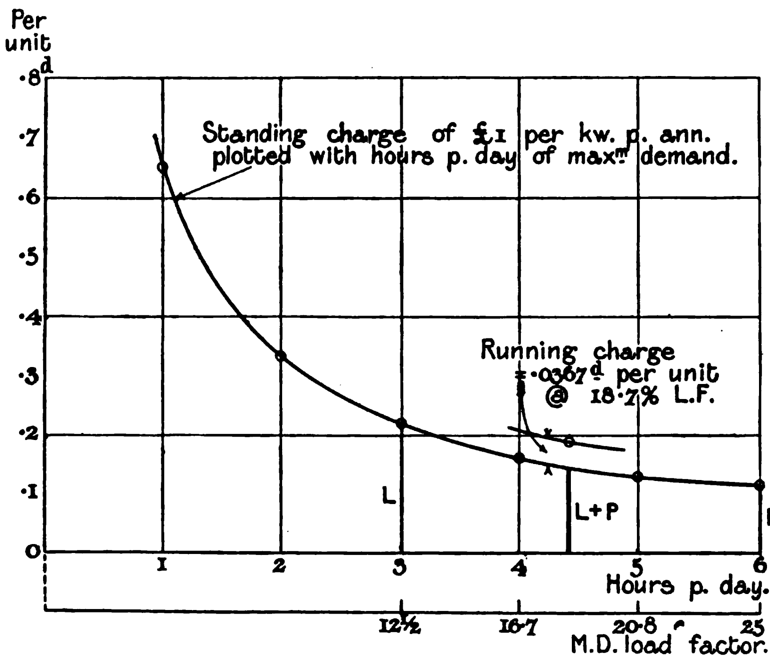

FIG. 3.

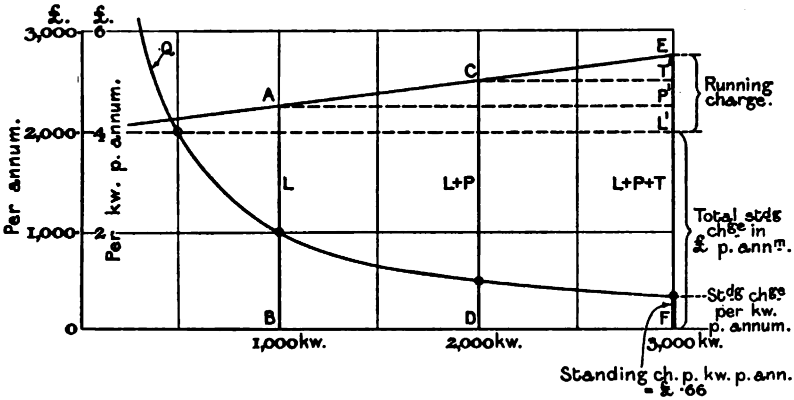
£.
£.
3,000
6
2,000
4
1,000
2
0
Per annum.
Per kw. p. annum.
Q
A
C
E
T'
P'
L'
Running charge.
L
L+P
L+P+T
Total stdg chge in £ p. annm.
Stdg chge per kw. p. annum.
B
D
F
1,000kw.
2,000kw.
3,000 kw.
Standing ch. p. kw. p. ann. = £ ·66

FIG. 4.

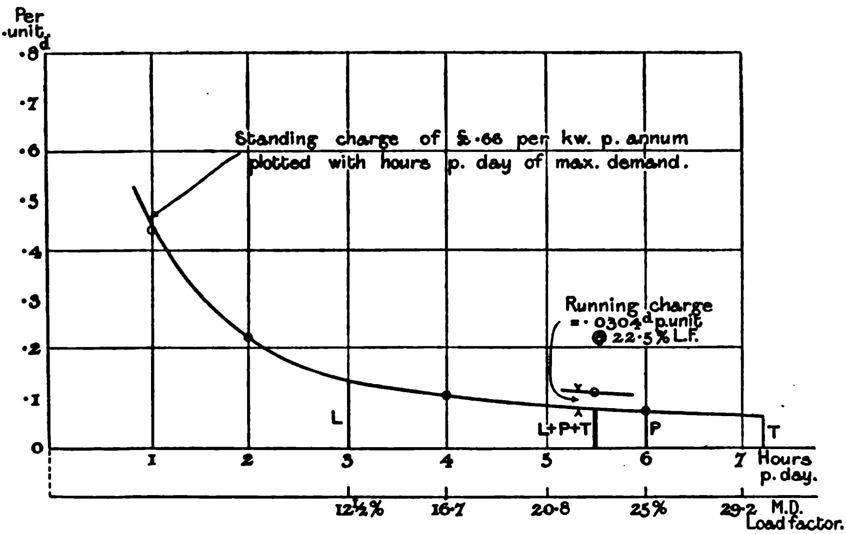
Per unit.
·8d
·7
·6
·5
·4
·3
·2
·1
0
Standing charge of £·66 per kw. p. annum plotted with hours p. day of max. demand.
Running charge = ·0304d p.unit @ 22·5% L.F.
L
L+P+T
P
T
1
2
3
4
5
6
7
Hours p. day.
12½%
16·7
20·8
25%
29·2
M.D. Load factor.

FIG. 5.

a more usual figure in the class of station we are considering, let us increase the values of Fig. 5 by 33 per cent., and we get, for price per unit sold :

Lighting, running expenses = 0·04d.; standing expenses = 0·20d.
Power „ „ = 0·04d.; „ „ = 0·10d.
Traction „ „ = 0·40d.; „ „ = 0·08d.

Average Combined Rate (for equal kilowatts):
Running Expenses = 0·04d.; standing expenses = 0·109d.
Average Combined Rate (for equal numbers of units):
Running expenses = 0·04d.; standing expenses = 0·126d.

When the numbers of units are not equal, the method adopted must take account of this, as in the table which follows.

In the case of large systems having substations, the wages at the substations may, without great error, be lumped together with those incurred in connection with distribution, and the whole classed as standing charges. Or, if desired, the substation wages may be analysed in the manner already indicated for the generating station.

When the load is of the nature of a "restricted-hour" load, it will be evident that, so long as it is also restricted in *amount*, no charge on account of wages is debitable, the expenses of running the station being in no way enhanced on account of the new load taken on.

4. *Repairs and Maintenance.*—After the expenses of repairs to mains, E.H.T. feeders, services, meters, buildings (main and substation, including also offices), pipework, conveyors, cranes, stokers, economisers, condensers, pumps, switchboards, auxiliary plant, substation batteries, etc., are deducted, most of which are almost independent of the number of units turned out by the station, we have left for consideration repairs on a proportion of plant which may perhaps represent one-third of the total capital cost. When one has further eliminated the expenses due to accidents—which may frequently wreck an engine or a generator in a few moments—or those due to breakdowns through failure of insulation, or short circuits, in electrical plant or apparatus, it will be seen that we can only fairly debit to running charges that portion of repairs—probably about one-ninth of the whole—which is somewhat in proportion to the actual number of units turned out by the station, such as renewals of commutators, brushes, engine brasses, piston rings, boiler tubes, grate bars, etc.

The money values and the lives of these parts are capable of pretty easy estimation, for any particular station, and the author submits that such should be the basis on which the principal part of the running charge for repairs is based. After a margin of, say, 25 per cent. has been added to this charge, to cover incidentals in condensers and auxiliaries, I submit that the whole of the other costs incurred in repairs and renewals should be lumped together and called the "Standing Charge."

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Adopting the above suggested fraction of the total cost of repairs (viz., one-ninth) as being that due to running charges alone, and remembering that the standing charge has, in the case of a combined lighting, power, and traction load, to be divided among the three classes of load in the inverse proportion of their (station) load factors, let us roughly apportion these for a comparatively small station, having a maximum output of, say, 2,000 k.w. (1,000 lighting, 500 power, and 500 traction).

The combined charge for such a station is frequently of the order of 0·30d. per unit sold. This would give:

Lighting, running charge = 0·033d.; standing charge = 0·422d.
Power " " = 0·033d.; " " = 0·211d.
Traction " " = 0·033d.; " " = 0·169d.

Average Combined Charge (for equal numbers of units):
Running charge = 0·033d.; standing charge = 0·267d.
Combined charge = 0·30d.

Before leaving the subject of repairs, an attempt to verify the above assumed figure of 0·033d. for the running charge is desirable.

The capital outlay for a maximum demand of 2,000 k.w. would be, or the station alone (*i.e.*, exclusive of feeders and mains), about £60 per kilowatt of maximum demand, or £120,000; and for boilers and running plant containing wearing parts, say £50,000.

The plant would turn out annually 2,000 k.w. × 1,972 units per kilowatt = 3,944,000 units (22½ per cent. load factor).

Taking the cost of the parts likely to be continuously under renewal, and in some measure in proportion to the number of units turned out of the station, such as grate bars, piston rings, boiler tubes, economiser tubes, condenser tubes, brasses, packings, commutators, brushes, to amount to, say, 5 per cent. of the value of the working plant in capital cost, *i.e.*, to £2,500, and allowing an average life for these wearing parts (which, be it remembered, include the wearing parts of the spare units of generating plant) of, say, five years, we find that an allowance of 1 per cent. per annum of the capital cost of the boilers and running plant would on the average be a fair sum with which to debit the running cost.

Now, 1 per cent. per annum on £50,000 is £500 per annum, and hence we get the running cost per unit, viz.:

$$\frac{£500 \times 240}{3{,}500{,}000 \text{ units}} = 0{\cdot}034\text{d. per unit,}$$

which sufficiently confirms the figure above assumed.

In the case of a restricted-hour load (subject to a restriction also as to its amount), the charge debitable to such a load is virtually only the "running charge" of the interest-paying motor load (viz., 0·033d.).

5. *Other Charges.*—To investigate in detail the other charges of the modern municipal station—interest, sinking fund, depreciation and

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renewals, management, office expenses, rent, rates and taxes, etc.—would add too greatly to the length of this paper.

It may suffice to say that the great bulk of these charges, probably 95 per cent. of them, bear no direct relation to the number of units sold. An exception may, however, be made in the case of office charges, where perhaps 10 per cent. is chargeable to running expenses. On the other hand, this charge does not occur in connection with a traction load.

The method already indicated for determining the proportion of standing and running charges for wages can be applied, where desired, to any or all of the above.

Apportionment of Total Charge to Lighting, Power, and Traction.

We have now sufficiently indicated a method of obtaining the relation existing between "running and standing" charges in the more important items of coal, petty stores, wages, and repairs; and the way in which the combined charges are made up for a given station for lighting, power, and traction; whether the units sold in all three cases are equal, or whether they are in proportion to the load factors of the several loads. Let us now endeavour to apply these results to the more complicated case where the numbers of units supplied for lighting, power, and traction bear no relation whatever to one another.

We will assume that, in the case of the station whose charges it is desirable to investigate, the approximate running cost has already been obtained, in the manner indicated, for each successive item comprising the *combined* expenses.

We will assume also that the combined operating expense of the station is known, and the combined charges to be made per unit to provide for all items of expense. What we desire to know is, how to proportion the charge per unit among the three classes of load: lighting, power, and traction.

For simplicity's sake, let us take the figures already arrived at for running costs (multiplying by 1·25 to reduce to per unit sold), viz.:—

Coal = 0·16d. × 1·25 = 0·20d.; petty stores = 0·02d.; wages = 0·04d.; repairs = 0·033d.; sundries = 0·023d. Total = 0·316d. per unit sold.

As an example let us apply these figures—though, as already stated, they are too high for a station of this size—to the Liverpool costs for 1904. The number of units sold for lighting, power, and traction were approximately 8,300,000, 2,054,000, and 19,000,000; total, 29,350,000, approximately.

The revenue obtained was £229,677, or an average figure, over all three classes of the supply, of 1·88d. per unit.

Let x, y, z be the three rates (for the standing charges) required to be obtained. First deduct from the 1·88d. the sum of the running charges (1·88d. − 0·316d. = 1·564d.), and we have:—

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Lighting	8,300,000 units at xd.	= £	a	(?)
Power	2,054,000 „ at yd.	= £	b	(?)
Traction	19,000,000 „ at zd.	= £	c	(?)
Total combined ...	29,354,000 units at 1·564d.	= £191,000		

From the above we can easily deduce the rates (standing charges) x, y, and z, bearing in mind that they are in the inverse ratios of the load factors 12½, 25, and 30 per cent.; hence the quantities composing the total of the standing charges (£191,000) are obtained.

These rates will be found to be respectively 2·71d., 1·36d., and 1·09d. per unit sold, to which must in each case be added the running cost = 0·316d.; making respectively 3·02d., 1·67d., and 1·40d. per unit sold for the combined charge.

It may be said, as against the acceptance of these figures, that I have taken the load factors for power and traction too low, and that 30 per cent. and 40 per cent. are nearer the mark. The effect of taking these latter values would be to give the following values to x, y, and z, viz., 3·04d., 1·26d., and 0·95d., to which adding 0·316d. as before, we get 3·35d., 1·57d., and 1·26d. per unit sold for the combined "running" and "standing" charges for the lighting, power, and traction loads respectively. It is interesting to note that the price charged for traction at Liverpool during the year in question was 1·16d., which is in fair agreement with my 1·26d., bearing in mind that the latter figure includes a share of office expenses which, of course, were not incurred, and that the running costs, as already explained, are purposely taken too high. The interest charges on traction and lighting cables, etc., would, of course, also have to be distinguished and properly debited to get the true traction charge.

What I wish, however, specially to emphasise is the large standing charge debitable to the power load, viz., 1·26d., on the most favourable basis, and assuming values for the "running charge" which would certainly be lowered in a large station like Liverpool, at the expense of an increase in the standing charge.

I also wish to call the attention of central station engineers to the enormous possibilities of development opening to them, if these "standing charges" can in any way be cancelled or reduced, and if it be conceded that the "running charges" are as low as I have put them.

The attached table, worked out some time ago on the basis of deducting the whole of the coal charges and calling everything else "standing charges" (a procedure not so far wrong, as regards proportion, as might appear), is given in the hope of eliciting further discussion, though it is avowedly only a first approximation.

Internal Diversity Factor—an Overrated Asset.

Many electrical engineers have seen, in what we may call the "Internal Diversity Factor" of the motor load, the supposed key to the

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TABLE I.

NOTE.—*Fuel costs and petty stores are not included in the figures given below.*

	Load Factor.	Charge for Interest and Sinking Fund (averaged over all classes of Load).	Wages and Repairs.	Rates, Rent, Taxes, Management Salaries, and Office.	Net Profit.	Average Total Charge (excluding Fuel).	Ratio Power Units. Light Units.	Ratio Power and Lighting Units. Traction Units.	Charge Debitable to Power Units* (excluding Coal).	Charge Debitable to Lighting Units (excluding Coal).	Charge Debitable to Traction Units (excluding Coal).
	Per cent.	d.	d.	d.	d.	d.			d.	d.	d.
Manchester (lighting and traction combined) ...	21·1	0·78	0·36	0·20	0·33	1·67	2 : 3	2 : 3 : 6	1·44	2·88	1·15
Liverpool (lighting and traction combined) ...	22·8	0·74	0·19	0·25	0·39	1·57	2 : 8	2 : 8 : 20	1·38	2·75	1·10
Bradford (lighting and traction combined) ...	24·6	0·73	0·34	0·21	0·02	1·30	2 : 2	2 : 2 : 7	1·22	2·46	0·98
Sunderland (lighting and traction combined) ...	*18·8*	*0·78*	*0·28*	*0·27*	*0·05*	*1·38*	*2 : 1⅓*	*2 : 1⅓ : 1⅔*	*1·15*	*2·30*	*0·92*
Glasgow (lighting and power)	*15·1*	*0·75*	*0·32*	*0·35*	*0·46*	*1·88*	*2 : 5*	—	*1·09*	*2·18*	—
Sheffield (lighting and power)	12·1	2·16	0·31	0·22	0·06	2·75	2 : 5	—	1·59	3·20	—
Leeds (lighting and power)	*15·6*	*1·65*	*0·28*	*0·25*	*0·08*	*2·26*	*2 : 5*	—	*1·31*	*2·63*	—
Glasgow (trams)	30 (estimated Manchester)	1·32	0·16	—	—	—	—	—	—	—	—

* On basis of 25 per cent. load factor for *power*, 12 per cent. for lighting, and 30 per cent. for trams; and charges assumed *to vary strictly in inverse proportion of load factor.*

problem of cheap supply; imagining that the charge per unit as determined at the station would have to be divided by the diversity factor, before the charge to the consumer would be arrived at, for the reason that the standing charge per annum per kilowatt of consumer's plant is undoubtedly less than that per kilowatt of maximum demand (at the station), in that proportion.

As I made this same mistake in my paper on "Standby Charges" without it being challenged, it seems probable that it is very generally accepted. Indeed, the discussion on that paper showed clearly that there was this tendency. After careful consideration of this point, however, I am convinced of the fallacy of the idea that the "internal" diversity factor of the motor load in any way reduces the charge per unit to be made to the consumer. On the contrary it somewhat increases it.

Let it be clearly understood that we are speaking of the fluctuations of the loads of the individual motors, taken over short periods of time such as a quarter-hour or so. That is to say that, while A's motor is perhaps working at full load for the period considered, B's motor is running empty, with the result that the demand on the station during that period is only half that represented by the joint rated H.P. of the two motors, *i.e.*, the diversity factor is $=2$.

I am not referring to an inequality of the motor load "humps" (at the station) in the morning as against the afternoon, caused by diversity factor; which, so far as I have been able to ascertain, does not exist to any appreciable extent. This inequality was referred to by Mr. Wright, in the discussion already alluded to, and no doubt where it exists in such a form that the afternoon "hump" is *less* than the morning "hump" it is entitled to consideration to the extent by which it removes the superposed motor load from the lighting "peak." But this case is only a mild form of a "restricted-hour" load, and as such can be dealt with on similar terms.

An example will probably make the above argument clearer, viz., that the charge per unit to the consumer is not reduced on account of "internal" diversity factor.

Take the case of four motors, each of 100 rated H.P. on the premises of four consumers A, B, C, and D, and working intermittently at their full rated load for, say, $2\frac{1}{4}$ hours $\times$ $5\frac{1}{2}$ days $= 12\frac{3}{8}$ hours per week (*i.e.*, 1,235 H.P. hours per motor per week out of a possible 16,800 H.P. hours) or at a 7·35 per cent. load factor.

The maximum H.P. at the station (neglecting losses in transmission) is 100 H.P., and the (limiting) diversity factor is, for this load factor, $=4$.

Hence station load factor $= 4 \times 7{\cdot}35$ per cent. $= 29{\cdot}4$ per cent.

In other words we have 400 H.P. connected up, and only 100 H.P. demanded at the station.

For the sake of simplicity let us call this 100 k.w. at the station busbars.

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Then: Units delivered to busbars per annum—

$$= 100 \text{ k.w.} \times 8{,}760 \text{ hrs.} \times \frac{29.4}{100} = 254{,}000 \text{ units.}$$

Let the capital cost of the station, mains, and services be taken at £10,000 = £100 per kilowatt of maximum demand at station.

Then, taking interest and sinking fund and reserve fund at 7½ per cent. (0·075).—

$$\text{Cost per unit} = \frac{£10{,}000 \times 0.075 \times 240}{254{,}000 \text{ units.}} = 0.71\text{d. per unit.}$$

Interest, sinking fund, and reserve fund charge per kilowatt of maximum demand at station $= \frac{£750}{100 \text{ k.w.}} = £7$ 10s. per kilowatt.

Other fixed charges assuming "total costs" = 1·0d. (after deduction of ¼ per unit for running charges = 0·75d.)—

$$= \frac{0.75 \times 254{,}000}{240 \times 100 \text{ k.w.}} = \frac{£795}{100 \text{ k.w.}} = £7 \text{ 19s. per kilowatt.}$$

Total fixed charge at *station* = £7 10s. + £7 19s. = £15 9s. per kilowatt of maximum demand; or total fixed charge per *consumer's* kilowatt $= \frac{£(750 + 795)}{400 \text{ k.w.}} = \frac{£1{,}545}{400} = £3$ 17s. per kilowatt.

Treating this charge on the maximum demand principle, we get: £3 17s. per kilowatt of consumer, on 100 k.w., as equivalent to a daily charge per unit of—

$$\frac{925\text{d.}}{(12\tfrac{3}{8} \times 52 \text{ wks.})} = \frac{925}{643 \text{ hrs.}} = 1.46\text{d.}$$

Add: Running charge, as above adopted = 0·25d.

Total = 1·71d.

But from the station point of view:—

Total cost per unit at station (as ascertained earlier) = 0·71d. interest, etc., + 0·75d. other fixed charges + 0·25 running charges = 1·71d.

Total revenue = 254,000 units at 1·71d. = £1,810 per annum.

And from the consumer's point of view:—

Units sold per consumer—

$$= 100 \text{ k.w.} \times 8{,}760 \text{ hrs.} \times 7\tfrac{1}{4} \text{ per cent. (L.F.)} = 63{,}500 \text{ units.}$$

Revenue per consumer = 63,500 units at 1·71d. = £452 10s.

And: 4 consumers at £452 10s. = £1,810 = the sum required to be raised annually.

Hence the price to be charged is the same, per unit, whether taken at the station or as made at consumer's premises, and diversity factor benefits nothing.

Summarising:—

We have—

Cost per unit to consumer = 1·71d. (1·46 + 0·25).

Cost per unit at station = 1·71d. (0·71 + 0·75 + 0·25).

Hence it is *wrong* to divide the charge per unit obtaining at the station by the diversity factor in order to get the charge to be made to

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the consumer; and the assumption that consumer's charge varies inversely with diversity factor is an incorrect one.

I have taken the very best case, for the consumer's L.F. considered, *i.e.*, I have neglected "unrealised diversity factor."

Taking the same station costs, I might have added a fifth consumer, with the same result.

The consumer's L.F. coming down to 5·89 per cent.

The consumer's charge per kilowatt coming down to £3 2s. per kilowatt.

The consumer's charge per unit remaining, at

$$\frac{925 \times 0·8}{643 \times 0·8} = 1·46 + 0·25 \text{ running charge} = 1·71.$$

The result coming out just the same as for the four consumers, though the diversity factor is 25 per cent higher.

In the above example the consumer's load factor is only 7·35 per cent., and it has been assumed that a station load factor of 29·4 per cent. would be obtained with four such consumers, each accommodating one another, and the station, to the utmost conceivable extent (over an ordinary nine-hour day) resulting in a diversity factor of 4. This is the figure which I suggested as the limit for a load having a 7½ per cent. load factor, in my paper on "Standby Charges," which, together with its corollary, that the average consumer's load factor × diversity factor = station load factor (in the limit), was severely criticised at the time, but has since been proved to be correct, having been checked by application to numerous stations throughout the country.

As a matter of fact, it is extremely unlikely that a diversity factor of 4, and hence station load factor of 29 per cent., would be obtained, owing to "unrealised diversity factor"; but, even if it were, the case worked out shows that it is better for low costs per unit, to have a single 100-H.P. consumer working continuously at 100 H.P. during the working hours of an ordinary day, than to have a number of consumers of poorer load factor, though giving a high diversity factor.

Combined Diversity Factor.

A treatment of the three classes of load absorbed at the station (lighting, power, and traction), in a similar way to the loads of three individual power consumers, would show: (1) that the combined diversity factor at any moment is equal to the sum of the three maxima (at *whatever* hours they occur) divided by the maximum observed joint demand at that moment; and would probably show (2) that the minimum combined diversity factor, taken over a given cycle of, say, twenty-four hours, when multiplied by the average of the three load factors, will (in the limit) be equal to the resultant combined load factor, taken over the same period; also (3) that the combined diversity factor is (in the limit) inversely proportional to the

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average load factor, *i.e.*, when the average load factor of the three loads is 30 per cent. the average combined diversity factor will be 3⅓ (or less), when the L.F. is 20 per cent the D.F. will be 5 (or less), and so on.

Diversity Improvement Factor.

The nearness with which the product of the diversity factor and the average load factor agrees with the combined load factor

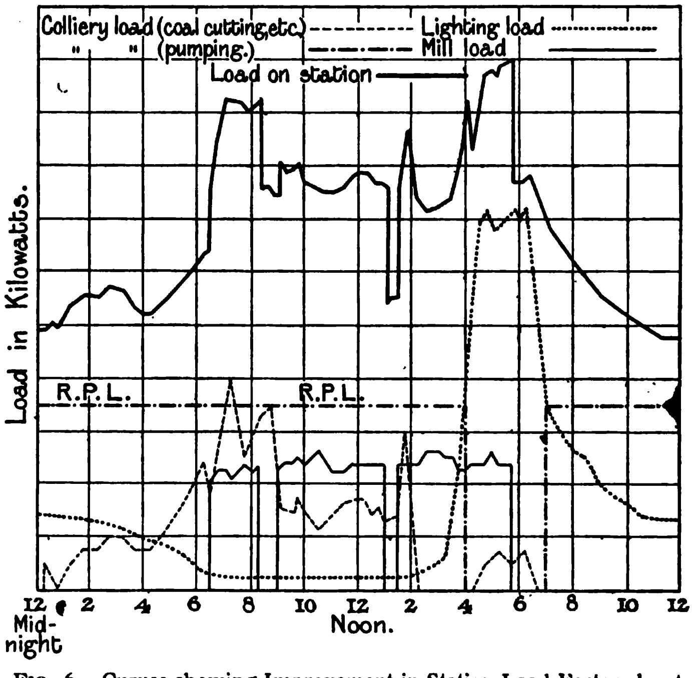

Fig. 6.—Curves showing Improvement in Station Load Factor due to Consumers' Diversity Factor.

might be called the "diversity improvement factor" of the station, and represents the extent to which the valleys in one class of load are filled by the peaks in the other two classes, and *vice versâ*. The object of the introduction of a restricted-hour system of charging is to improve this figure.

In this connection the curve marked R.P.L. in Fig. 6 (taken from the *Electrician* of September 15, 1905) may be referred to, as an interesting indication of the way in which some of our power companies are reckoning on developing their load by means of "restricted-hour" charges.

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"Non-Interest-Paying" and "Ideal" Loads.

It will be generally conceded that if a load could be found for our generating stations which would at all times accommodate itself to the amount of spare capacity available in the generating stations and mains, it should not be chargeable with interest, etc., charges; unless it is proposed to make the new load bear part of the interest charges now borne by the existing light and traction loads.

On further consideration it will, I think, be conceded that the new load should not be debited with any standing charges that are now paid by the other loads; but only with such extra standing charges as may be incurred by its introduction. Of course, in the case of interest charges, if it should be found that the new load introduced extra items of capital expenditure, say in connection with services or mains, it should be debited with these.

It may also be postulated that, in addition to paying interest charges on such extra capital, the load should bring in a margin of "nett profit" also, to make it worth the catering for.

A restricted-hour load, advocated by me in a previous paper and not infrequently catered for, is an attempt partly to fulfil the above conditions; but, obviously, it suffers from serious limitations owing to day fogs, as well as having great drawbacks from the point of view of the customer.

Storage.

It will be fairly obvious that the only way to provide a load of the above greatly-to-be-desired nature (*i.e.*, not merely a "restricted-hour" load) and one which shall not, at the same time, inconvenience the customer, is by means of storage of the power, either at the sub-station or, failing that, at the main station. But the weak point of this scheme is its financial aspect. If we put the batteries either at the main station or at the sub-stations, we must still charge consumers all existing interest, etc., charges, as well as all "standing" charges incurred outside the station; and the question then resolves itself into the capital charges, working expenses, and maintenance of the cells (including transformation losses), being less, or more, than the interest and standing charges saved on the generating plant.

Personally, I am of opinion that in most cases the balance in favour of the employment of the cells under such conditions is very small, the scheme being seriously hampered by those interest and other standby charges which are *not* cancelled by the introduction of the cells; also by the fact that it is impossible to differentiate between power and light, and between existing consumers and those on the new system; consequently the experiment would have to be tried on a very large scale, under conditions of minimum efficiency; in addition to which the price to existing consumers could not well be lowered, as a very large capital expense (partaking of the nature of an experiment) was being undertaken. We are thus led to consider the question of

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placing the cells on the consumers' premises, and it is in this direction that I believe success will most probably be attained.

At first the difficulties of capital cost of cells, and maintenance, as well as the supply voltage and the number of cells consequently necessary on each consumer's premises, may seem insuperable; but, on the other hand, there are the advantages of having a reserve supply on the premises, and recent accidents in London and elsewhere show that these advantages are very real.

The standing and interest charges saved to the station and mains are of the order of ¾d. to 1¼d. per unit, while the charges incurred on account of the cells are not above ¼d., and in most cases this would provide for a complete renewal of the plates every five years.

To describe the methods by which I expect to avoid the difficulties connected with the placing of the cells on the consumer's premises, would be going outside the scope of the present paper.

Conclusions.

1. The total charge debitable on account of running costs is much lower than is generally considered to be the case, varying from 0·30d. in medium-sized stations to 0·20d. in the largest ones.

2. For an "ideal" load, this includes all items of expense, right up to consumers' terminals; provided the mains already exist.

3. The coal charge is far away the heaviest item of the running expenses.

4. The "running" part of the coal charge is easily estimated for any one town as against any other; and for a given class of coal is sensibly constant over a large variety of stations.

5. A large "internal diversity factor" on a motor load may be a positive disadvantage.

6. Any thing tending to improve the combined diversity factor of the three classes of load is to be strenuously encouraged.

7. Storage on consumer's premises, if it can be proved to be practicable, is the only known means of providing a load which could be made to at all times accommodate itself to the amount of spare capacity available from the other two classes of load; thus realising the highest average "combined diversity factor" possible.

8. The reduction of charge which could be made in many stations, by merely treating the "unproductive capital" charge in the way indicated by the author in his paper on "Standby Charges," is quite appreciable.

The last point, though not discussed in the present paper for lack of space, is introduced to make the paper more complete.

APPENDIX.

The following notes may be of interest.

Table II. shows, in a tabulated form, the average loads on a lighting

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TABLE II.

Period.	Average Loads over Periods of 500 hrs.	Running Sets.	Units Generated.	Capacity of Running Sets.	Capacity of Whole Station (incl. Spares.)	Running Plant Load Factor.	Plant Load Factor.	Maximum Demand Load Factor.	Coal Consumption of Sets at 7 lbs. Steam per lb. of Coal.	Steam Range and other Constant Losses at 10% of Maximum Station Capacity (incl. Spares.)
Hours.	Kilowatts.	K.W. K.W.		Units in 500 hrs.	Units in 500 hrs.	Per Cent.	Per Cent.	Per Cent.	Lbs. per Unit.	Lbs. per Unit.
500	3,400	2 × 500 ; 3 × 1,000	1,700,000	2,000,000	2,500,000	85·0	68·0	85·0	3·3	0·39
500	2,400	1 × 500 ; 3 × 1,000	1,200,000	1,750,000	2,500,000	69·0	48·0	60·0	3·4	0·54
500	1,720	1 × 500 ; 2 × 1,000	860,000	1,250,000	2,500,000	69·0	34·0	43·0	3·4	0·76
500	1,200	1 × 500 ; 1 × 1,000	600,000	750,000	2,500,000	80·0	24·0	30·0	3·3	1·05
500	800	1 × 500 ; 1 × 1,000	400,000	750,000	2,500,000	53·0	16·0	20·0	3·8	1·58
500	600	1 × 1,000	300,000	500,000	2,500,000	60·0	12·0	15·0	3·7	2·20
500	520	1 × 1,000	260,000	500,000	2,500,000	52·0	10·4	13·0	3·8	2·55
500	440	1 × 500	220,000	250,000	2,500,000	88·0	8·8	11·0	3·3	3·00
500	380	1 × 500	190,000	250,000	2,500,000	76·0	7·6	9·5	3·3	3·52
500	340	1 × 500	170,000	250,000	2,500,000	68·0	6·8	8·5	3·4	3·87
500	300	1 × 500	150,000	250,000	2,500,000	60·0	6·0	7·5	3·5	4·40
500	260	1 × 500	130,000	250,000	2,500,000	52·0	5·2	6·5	3·8	5·00
500	220	1 × 500	110,000	250,000	2,500,000	44·0	4·4	5·5	4·0	6·00
500	200	1 × 500	100,000	250,000	2,500,000	40·0	4·0	5·0	4·2	6·60
500	160	1 × 500	80,000	250,000	2,500,000	32·0	3·2	4·0	4·6	8·25
500	140	1 × 500	70,000	250,000	2,500,000	28·0	2·8	3·5	4·9	9·40
500	140	1 × 500	70,000	250,000	2,500,000	28·0	2·8	3·5	4·9	9·40
250	120	1 × 500	30,000	125,000	1,250,000	24·0	2·4	3·0	5·5	9·40
8,750 (Total.)	742 (Average.)	—	6,640,000	10,125,000	43,750,000	65·5 (True Average.)	14·7 (Average.)	18·5 (Average.)	3·9 (Average.)	4·3 (Average.)

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station whose maximum observed demand is 4,000 kilowatts, plotted over the whole year of 8,750 hours. This is applied to the station considered in Fig. 1 of the paper, and the third column shows the

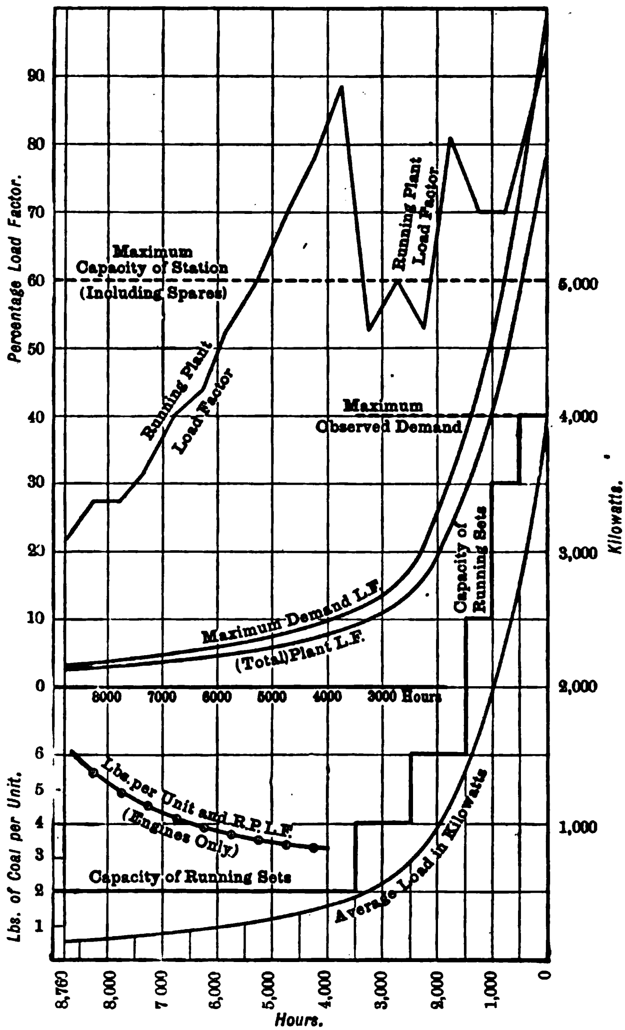

FIG. 7.—Results obtained from Table II.

number of running sets for each period of 500 hours. The fourth column shows the units generated, on the average loads of column (2). The seventh column is the ratio of columns (4) and (5), and gives the

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running plant load factor for different periods of 500 hours during the year. The eighth column gives the plant load factor as defined in the paper; and the ninth column the maximum demand load factor. The tenth column gives the lbs. of coal per unit, for the engines only, corresponding to the running plant load factors of column (7). The

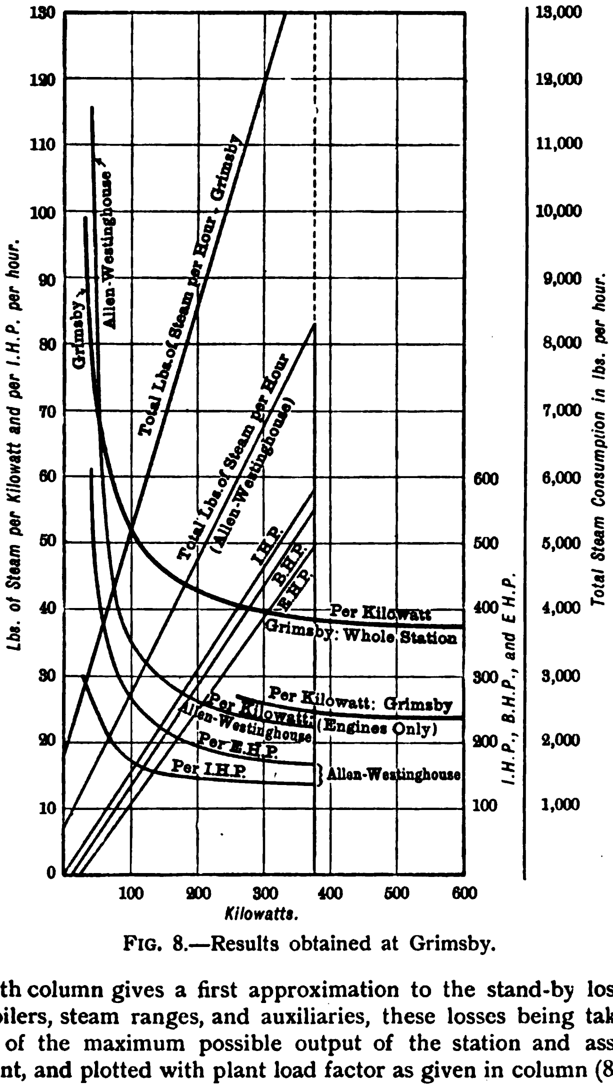

FIG. 8.—Results obtained at Grimsby.

eleventh column gives a first approximation to the stand-by losses of the boilers, steam ranges, and auxiliaries, these losses being taken in terms of the maximum possible output of the station and assumed constant, and plotted with plant load factor as given in column (8).

Fig. 7 represents graphically, in the form of curves, the results given in Table II.

Fig. 8 shows the actual results obtained at Grimsby* for a station having sets of 200-k.w. capacity, and is comparable with Fig. 1 of the author's paper. On the same slide are shown the results for a single Allen-Westinghouse 375-k.w. set.†

Fig. 9 represents, in a graphic form, the cost per unit incurred by installing accumulators on consumers' premises, plotted with the load

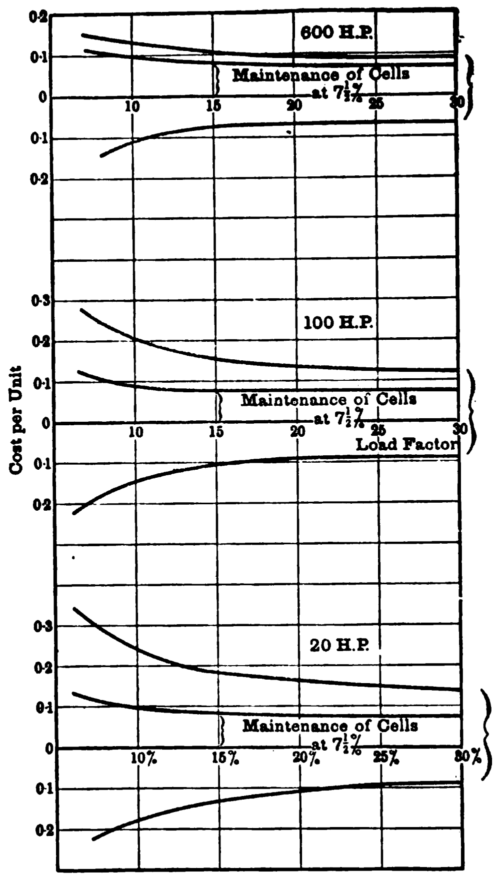

FIG. 9.—Cost with Accumulators on Consumers' Premises.

factor of the consumers' motors. The curves are given for three different sizes of installation. Interest and sinking fund is taken at 6 per cent. on both cells and transformation gear, and is plotted below the datum line.

* *Electrician*, vol. lv., pp. 41–45, 1905. † *Electrician*, vol. lii., pp. 730–731, 1904.

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Discussion.

Mr. W. A. Vignoles (*communicated*): While I do not agree with the author in all the details of his working, yet I am in substantial agreement with him in his general conclusions. Mr. Vignoles.

His conclusion that the running charges in a moderate sized station work out at from 0·2 to 0·3 of 1d. is corroborated by the figures obtained in Grimsby from the working of quite a moderate sized plant, and in my opinion shows that existing supply stations, although of small size, can offer very low rates for a supply of electrical energy if the load factor is sufficiently good. For instance, in supplying power to a flour mill where the load is absolutely steady during the twenty-four hours, and the mill runs six days out of the seven, supply could be given at less than ¼d. per unit and a handsome net profit would still be made, even if the works were of moderate size. This is assuming the power taken to drive the mill at about 300 H.P.

As regards the details of the running costs, I think the cost of coal is taken at rather a high figure; in fact, Mr. Taylor states that he has purposely done this, and the steam per kilowatt-hour, given on page 366 as 25 lbs., employing superheated steam and condensing, is very liberal. For a 500-k.w. set 160 lbs. steam pressure, 26-in. vacuum, I think engine makers would guarantee 21 lbs. with a moderate superheat. I am glad to see that, in connection with the coal used, Mr. Taylor suggests making the diagram, Fig. 1, from the actual tests in the works, rather than building it up as he did in his previous paper.

With regard to the wages, it appears to me that Mr. Taylor places too much to standing charges and not sufficient to running charges. I think that wages would work out at more than 0·0367d. per unit if this includes the cost of cleaning boilers, which is certainly a running charge, as it depends almost entirely on the total amount of steam generated.

Again, I think the cost of repairs chargeable to running charges is hardly sufficient, and his verification on page 372 contains too many assumptions to be of very great value.

As regards the diversity factor, I cannot understand how any one could suggest that the charge ascertained at the station should be divided by the diversity factor to find the amount chargeable by a particular power consumer. Considering the power load only, the charge per unit as determined at the station for the average supply must be the average amount to be charged to all power consumers. It is of no consequence to the works if the power supplied is given to four different consumers, each taking their supply for an equal portion of the day, if their loads do not overlap and there are no periods when no supply is being given, or if one consumer takes the whole quantity with the same maximum demand and the same load throughout the day. Mr. Taylor has made that point quite clear, but he still does not show the advantage from the diversity factor. If all power consumers took their maximum demand at the same time, the maximum demand

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Mr. Vignoles.

on the station would be increased and the rate of charge as ascertained at the station augmented considerably, and consequently all power consumers would have to be charged at rates depending on their load

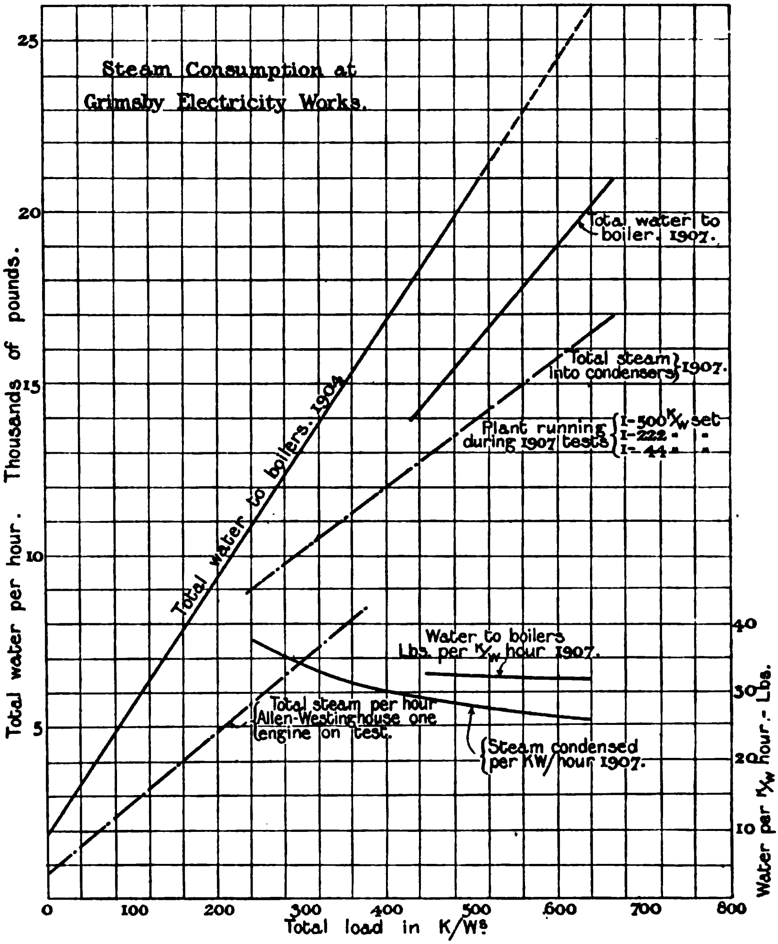

FIG. A.

factor, and the charges would have to be dealt with on the same lines as the charges to lighting consumers. Taking the example on page 377, the cases he mentions of motors running with a load factor of 7·35 per cent., if it was not for the diversity factor power, would have to be supplied to these motors at lighting rates on account of the poor load factor, but owing to the existence of the diversity factor it is possible to give them a price based on a load of 20 per cent.

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As regards a restricted hours' supply, I have had some years experience of this as an alternative to the ordinary rates, and find that it is suitable for certain trades, and at the present time there are over 300 H.P. in motors connected to the mains in Grimsby supplied on this system. It is certainly not suitable in all cases, and in towns liable to heavy fog such a system would have to be introduced very cautiously. The price fixed should also be a minimum charge, so that very small motors could not get the full benefit of the system, as users of such motors can very well afford to pay the ordinary rates. Mr. Vignoles.

In conclusion, I cannot agree with Mr. Taylor that it would be at all desirable to put storage batteries in consumers' premises. If storage batteries could be used efficiently, why not put them into sub-stations where they could receive careful attention? but personally I very much doubt if storage in this manner would pay.

Some curves are given in Fig. 8 which represent tests made in Grimsby in 1904 showing the steam consumption per kilowatt of load on the station at that date, and members may therefore be interested to see the curves prepared by me from tests made in 1907.

The curves show the total water to the boilers and the total steam condensed for various loads. It will be seen that the plant is now more economical, this being due to a larger set having been installed, and to electrically driven condensing plant being in use in place of the steam driven. The water pumped in the boilers at 640 k.w. is 33 lbs. per kilowatt-hour, while the steam condensed is about 25·5 lbs. per kilowatt-hour. I have only drawn the curves between the points for which I have observations, but I hope to get tests during the course of the year through larger ranges of load.

I have added the curve for the Allen-Westinghouse set noted by Mr. Taylor.

Mr. S. E. FEDDEN (*communicated*): I have read Mr. Taylor's paper with special interest. In practice, however, I consider there may be a considerable difficulty in getting sub-stations on consumers' premises to take the batteries and accumulators suggested. I have found it none too easy to induce large users to grant the comparatively limited space and building accommodation needed for the static transformers on our own system. Mr. Fedden.

Since my previous communications with the author many hundreds of horse-power of motors have been added to my mains, and the figures for connections and average load go to show that the diversity of consumers' demands is maintained at a high figure. But I think the value of this factor would probably vary considerably in industrial towns with the nature of the business in which they are engaged. In Sheffield there is considerably more variety in the uses to which electric motors are applied than might be found in, say, a textile or mining district.

Mr. W. W. LACKIE (*communicated*): I note that on page 372, under the heading "Repairs and Maintenance," the author says that after deducting certain items "we have left for consideration a proportion of Mr. Lackie.

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Mr. Lackie. repairs which may perhaps represent one-third of the total capital cost." I assume he means one-third of the total cost only for repairs and maintenance. The whole object of the paper, I take it, is to show how we can hope to supply electrical energy at a lower figure by reducing (or canceliing as Mr. Taylor puts it) the standing charges, for our running charges are now getting as low as we can reasonably expect. The method most municipalities are adopting is to reduce the capital by writing off depreciation and sinking fund as largely as possible, and not by applying what profits there may be to the relief of local taxation or the subsidising in any way other municipal undertakings, as is done in some English towns. By reducing the capital through writing off sinking fund and depreciation, our costs per kilowatt will be lowered and consequently our standing costs will be lowered.

In Glasgow our capital cost per kilowatt has been reduced from £131 in 1898 to £75 in 1905, partly by writing off capital and partly by filling up our stations and so reducing the cost per kilowatt for land and buildings.

The most important point, however, and the point on which I do not agree with Mr. Taylor, is that stated on page 378, where be says that a supply of electrical energy cannot be given to four motors for less than 1·71d. per unit or £18 1s. 11d. per kilowatt of maximum demand. He assumes a capital expenditure per kilowatt of £100, which is equal to an annual charge of £7 10s. per kilowatt; but where does he get the other fixed charge equal to 1d. excluding ¼d. for running charges? On page 369 he puts the running cost per kilowatt at £1, so that, instead of £7 10s. plus £7 19s., it looks as if the figures should be £7 10s. plus £1, plus 2,540 units at 0·25d., or a total of £11 3s. for 2,540 units, which is equivalent to an average price of 1·05d. per unit. I need not point out that if the capital cost was £50 per kilowatt in place of £100 the above figure would be reduced to 0·7d. per unit. £15 9s. per kilowatt of maximum demand on the station, plus ¼d. per unit, shows on the face of it that there is an error somewhere. Power companies are to-day quoting £5 per kilowatt plus ¼d. per unit, and a common rate is 365 hours use of the maximum demand at 6d. and 1d. per unit for all further quantity, which is only equivalent to £7 12s. per kilowatt, plus 1d. per unit, and this rate we know pays. Mr. Taylor must also, I think, make some allowance in his argument for figures, for a twenty-four-hour day as well as a nine-hour day. In Glasgow, while our maximum demand on the station on the Friday before Christmas, 1905, was 16,000 k.w. the sum of the maximum demands as recorded on the consumers' demand indicators was 22,215 k.w.

I regret that I do not agree with the author's statements under his heading "Non-interest Paying and Ideal Loads." Any new load should bear some share of the interest, sinking fund, and depreciation of the plant required. Our American friends have encouraged and developed to an enormous extent the supply of electrical energy for lighting purposes. After 6.30 p.m. on to midnight and all-night lighting for the use of electric signs and for advertisement lighting

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generally they find they can supply profitably at a low rate. In Glasgow we have a fair number of works that run night and day, and a great many bakeries that commence work at midnight and stop at 8 a.m. Mr. Lackie.

This whole subject is unfortunately one that has to be dealt with by a mass of figures, and it is difficult to criticise these in any lucid or convincing way. The fact is, it is not a matter of a low figure per unit but the £ s. d. per kilowatt per annum received for the supply which is the true criterion of economy.

Mr. M. J. E. TILNEY (*communicated*): I am afraid I cannot agree with what may be called the foundation for the figures given by the author for coal costs. To show what I mean I have taken three stations at random from a group, not selecting them at all on account of results, but simply to illustrate three of the classes he deals with, namely, a station we will call No. 1, to illustrate a purely lighting station; another, No. 2, to illustrate a combined lighting and power station; and a third, No. 3, to illustrate a combined traction and lighting load. Mr. Tilney.

The plant capacity is: For No. 1, 360 k.w.; for No. 2, 600 k.w.; and for No. 3, 225 k.w., so that we might reasonably expect far worse results than are given in the paper for much larger stations considered.

No. 1 station is a south country town, a long way from the coalfields, and pays 16s. for a coal of only a very little higher calorific value than the slack quoted in the paper. The plant load factor, as defined in the paper, is only 9·4, the station load factor being 14·8, and the coal per unit generated is 5·21, this being the figure obtained for a whole year including all standby losses.

No. 2 station is in the north, near the coalfields, and pays 6s. 6d. for "small coal," as it is called locally, which is of about the same value as the other. The plant load factor is 9·9, and the station load factor is 19·15, the coal per unit, on the same basis as for No. 1, is just over 4·9 for the year.

No. 3 is fairly near the Midland coalfields, and pays 8s. 1d. for coal, which is again of about the same value. Its plant load factor is 25 per cent., its station load factor 25·7 per cent., and its coal 4·84 lbs. per unit.

In the case of No. 1, with the exception of a small domestic machine, there are no motors on the mains. The motor connections of No. 2 are 60 per cent. of the total connections, and in the case of No. 3 the traction load, reduced to equivalent connections, forms 90 per cent. of the total connections. It therefore seems to me that the figure of 8 to 12 lbs. per unit, given on page 367, is very much too high.

I remember even in the days of 1899 that a station in London, at which I was then working, used to expect to get down to about 5 lbs. for the year; we were using Welsh coal, it is true, but the station was being worked under fairly difficult conditions due to alterations, and the waste was awful.

I know a great many people who will not agree with the method adopted, but to those who do agree with the author the explanation of

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Mr. Tilney. the basis will be of very great value. I am afraid, however, that the unequal value of the units under the different headings will probably mislead an unwary person.

Mr. Bowden. Mr. J. H. BOWDEN (*communicated*): I have read the paper with a certain degree of disappointment. From the title one is naturally inclined to expect some interesting hints on central station economy, but I find in the concluding paragraph of the paper, the sole point of the subject, namely, the advocacy of storage batteries on consumers' premises, which promises nothing in the way of station economy—or, what is of equal interest to the electricity supply manager, a saving to the consumer.

I entirely disagree with the statement that storage on consumers' premises is the only known means of providing a load which could be made, at all times, to accommodate itself to the amount of spare capacity available from the other two "classes of load." I cannot conceive of any possibility of prevailing upon consumers to charge their batteries at the precise time at which the plant load factor drops below the economic stage, which I venture to compute at 80 per cent. I have found at Poplar that this is a favourable load, and one that is easily attained with a well-balanced power and lighting load. Granted that the economic load factor can be obtained without the introduction of storage batteries on consumers' premises, any saving to be effected must be by utilising reserve plant at an equally favourable load; but to do this the restriction must not only be as to the hours overlapping, but also in the event of breakdown of plant. This restriction I cannot conceive to be acceptable to any consumer, no matter how accommodating he may be to the ideals of the station engineer. To my mind the whole argument must be in the question, "Can we reasonably hope to find a class of consumer who is willing to accept supply only at such time as it is convenient for the undertakers to give it?" If so, then I for one am willing to consider the question of giving such a supply at a price equivalent to the value of the load obtained, which would certainly not be based on Mr. Taylor's system of calculation. And the return I should expect from such an ideal consumer would be the actual running cost, plus capital charges for service connections, establishment charges, and the due proportion of the annual surplus required for reserve fund.

However, I think the probability of obtaining this class of supply is so remote that I do not think it is worth the time required to discuss it, but I should like to remark briefly on one or two of the definitions used in the paper.

Plant Load Factor.—As the station load factor is the index to the standing charges per B.T.U., so is the plant load factor an index to the running costs, but the station load factor can only be calculated on the annual maximum demand, whereas the plant load factor can be arrived at over any period, no matter how short, and I find that the custom of calculating each shift is far more useful than taking it over the whole year, as Mr. Taylor suggests. A low plant load factor is

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often an indication of negligence on the part of the running staff, and the more often it is recorded, the closer vigilance can the engineer exercise over his running costs. Mr. Bowden.

The remaining load factors as set out by the author do not appear to me to have any bearing upon the subject of the paper, but I certainly think that the ratio of the total capacity of consuming devices connected, to the maximum demand on the station, is of paramount importance in determining a fair charge for each class of supply.

Wages.—I consider that it is most practicable to assume the whole of the generating wages as standing charges for the simple reason that the capacity of the station may be many times multiplied without materially increasing the running staff, but by increasing the size of the existing units, and by the use of mechanical labour-saving devices, the latter being provided out of capital, becomes at once a standing charge. It is quite safe to assume as standing charges any costs that do not necessarily increase with the output, and are solely controlled by the station load factor, namely, coal, water, stores, station maintenance, and distributing costs.

In conclusion, I should like to corroborate Mr. Taylor's figures regarding the possibility of raising steam, under the conditions named, from low grade coal at about 7s. 6d. delivered in London, by quoting the following extract from the Poplar Electricity Works steam consumption log sheet, for week ending February 1st, 1907:—

	Poplar.	Mr. Taylor.
Lbs. water per kilowatt	27·7	29
Lbs. steam used by generators	22·1	25
Lbs. used by pumps and radiation losses ...	5·6	4
Lbs. water evaporated per lb. coal	6·1	7
Lbs. coal per kilowatt-hour	4·55	4
Average steam pressure, lbs. per square inch	178	180
Average feed temperature	214° F.	210° F.
Average superheat	91½° F.	100° F.
Cost of coal per kilowatt-hour	0·253d.	0·16d.

The above results are combined from coal burned on chain grate and underfed stokers, and the average price of coal delivered into bunkers is 10s. 6d., with a boiler load factor of 57·7 per cent. Under test conditions I have obtained from slack, at 8s. 9d. per ton delivered, 7·45 lbs. water per lb. coal, actual, which nearly approaches Mr. Taylor's figure of 0·16d. per unit.

Mr. C. E. C. SHAWFIELD (*communicated*).—Though Mr. Taylor's paper deals with a subject in which I am specially interested, I find myself in almost total disagreement with his conclusions. Mr. Shawfield.

It has always struck me that he takes far too pessimistic a

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Mr. Shawfield.

view of the possibilities of electric supply, and were we central station engineers to accept his conclusions as correct it would practically mean that we should be entirely cut off from the possibility of entering into power supply on a commercial basis.

It must be remembered that the factor which determines the selling price of electrical energy for power purposes is the competition of other forms of motive power. If electrical engineers desire to obtain even the smallest share of the vast field of power supply, they can only do so by selling their electrical energy at a price which will enable it to compete on a commercial basis with suction gas, producer gas, Mond gas, town's gas, and steam, to say nothing of the various developments of the oil engine.

Further, they must be able to give a supply of electrical energy when and where it is required without any hampering restrictions as to the period of the day at which it may, or may not be used.

I am quite prepared to admit that the ideal motor load would be one which came on as early as possible in the morning and shut down just before the advent of the lighting peak. Unfortunately, however, this ideal is almost impossible of realisation, as the tendency, especially in the winter months, appears to be rather towards starting a little later in the morning and working later in the evening, with the result that between 4.30 p.m. and 6 p.m. the lighting and the motor loads overlap.

Under these conditions, therefore, a motor load must of necessity be charged with that proportion of the interest and sinking fund on capital and other standing charges which are directly incurred in order to supply it. I contend, however, that Mr. Taylor greatly over-estimates the proportion of standing charges which are directly allocable to motive power supply, and that so far from it being necessary to charge from 1½d. per unit and upwards for energy sold to power consumers, such energy can be supplied at a profit at a price of from 1d. per unit downwards in practically all cases where the ordinary working hours of the consumer are forty-eight per week and upwards.

I think it will be generally admitted that the majority of the central stations in the United Kingdom were primarily designed for the purpose of electric lighting, and that until quite recently nearly all extensions of these stations have been called for by developments in the lighting load, always excepting the cases where special extensions of plant have been required for traction purposes which, although supplied from the same station, must nevertheless be regarded as a separate and distinct load, inasmuch as it necessitates separate distributing mains and frequently separate generating plant. If, therefore, at the present time an undertaking of, say, 2,000-k.w. capacity decides to cater on a commercial scale for a motor load, it obviously must require an extension of the generating station, and also of the distributing system. Whether this extension is on the low-tension direct-current, or on the extra high-tension alternating-current system, it does not affect the principle at issue, but only the capital cost of

installation. The running costs also need not be affected by the choice of system. Therefore I contend that in estimating the cost of supply for motive power purposes such supply should only be charged with the capital expenditure incurred in regard to it, and that it should *not* be loaded with those standing charges which existed previous to its development, and which would have to be paid whether the motor load existed or not. Hence in an existing lighting station when quoting for a supply of motive power the following charges are those which should be taken into account:— Mr. Shawfield.

1. The interest, sinking fund, and reserve fund, in respect of the additional capital expenditure involved on buildings, plant, and mains.
2. The rent, rates, taxes, and insurance on the buildings, plant, and mains.
3. The additional wages necessary to operate the additional plant.
4. The annual cost of maintaining the additional generating and distributing plant in an efficient condition.
5. The additional expenditure on coal, oil, water, and stores.

The sum total of the foregoing items of annual expenditure divided by the annual units *consumed* for motive power purposes will represent the actual cost of delivering such supply at the consumers' premises. To this figure must be added the profit desired to be obtained.

If these principles are applied to the case of an existing station of, say, 2,000-k.w. capacity, situate in an industrial area with a population of 100,000 to 150,000 inhabitants, it can be shown that it is possible for that station to cater for motive power supply at prices ranging from 1d. per unit in the case of small manufacturers using, say, 12,000 units per annum down to 0·6d. per unit (or in some cases lower) in the case of large manufacturing works with a consumption of 2,000,000 units per annum and upwards. I have assumed that the conditions of generation are the same as those taken by Mr. Taylor, namely, that the station is equipped with condensing plant, and that bituminous slack of a calorific value of 11,000 B.T.U. can be delivered at the boiler fronts at a cost of 7s. 6d. per ton. For other conditions of site, and fuel cost, allowances must necessarily be made.

ADJOURNED DISCUSSION, MARCH 13, 1907.

Mr. J. A. JECKELL: We all wish to see electricity supplied at the lowest possible rate, because the lower the rate the larger would be the demand. A great deal can be said in certain towns in favour of a restricted hour demand. In a town where the supply is only required for lighting, it is of very considerable advantage, but where there is a large motor load during the day-time it will be less advantageous. The question as to the rate at which energy can be supplied during the day-time when in ordinary course of events the plant is standing idle is one needing careful consideration. I agree with Mr. Taylor in principle as Mr. Jeckell.

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Mr. Jeckell. to how this should be done, but I am not in absolute accord with him as to how it should be carried out. It seems to me that if we want to divide the running costs from the standby charges we must adopt another method. Let us assume that a station has a standby station ready and willing to supply the energy demanded. The boilers are in readiness, the pressure up to the normal, the engines turning round, and the men all at their stations. Every cost after that must be a running cost. Obviously practically all maintenance charges, all repairs, are running costs not standby charges. If the engines only turned round without supplying any energy the repairs on them would be practically nil. Mr. Taylor suggests as a basis a type of plant which can be bought now, but it should not be overlooked that the principles underlying the paper relate to certain stations which were laid down in the past in order to supply a lighting load. I venture to think the plant in those stations will not produce the energy at the cost per unit for steam or coal consumption given in the paper. It seems to me £250 for running charges in regard to wages is a very low estimate to cover the super-imposed power load of 1,000 k.w. The author seems to think we can not supply a power load under 1·67d. per unit, and on that point I agree with the remarks previously made by Mr. Shawfield. If we cannot supply a power load under the figure mentioned, then many of our accountants and quite a number of our balance sheets are wrong, but I venture to think figures speak for themselves. In the town with which I am connected we have super-imposed a power load upon a lighting load. In 1903 the number of units sold for lighting in Coventry was 454,000 and the power units 112,000. The total cost of these, according to Mr. Taylor's figures, amounts to £8,139, which shows a remarkable agreement with the actual cost, namely, £8,148. But we have to remember that the actual loss made by the undertaking was £189. Taking the year 1906, according to Mr. Taylor's figures, the total cost ought to be £26,000; the actual cost was £17,000. The revenue obtained from the power units was only 1·12. The actual experience, therefore, seems to show that there is something wrong with regard to the calculation of the power figures, for supplying at 1·12 they made a profit of £2,240.

Mr. Kemp. Mr. J. P. KEMP: The term which Mr. Taylor calls the "plant load factor" is the original load factor enunciated by Colonel Crompton a good many years ago, and he then defined it as the relation of the actual output of a plant to what would be its output if worked continuously day and night for the same period. We have been rather taken off the track by the load factor, which now appears in the columns of the *Electrical Times* week by week, and was based on the maximum demand instead of on the capacity of the plant installed. Writers of papers and technical articles never give the slightest inkling as to which load factor they mean, consequently the results given are little or no guide to anybody. Although I am grateful to Mr. Taylor for introducing these definitions, I think that the term plant load factor should really be true load factor. Mr. Taylor contends that the load

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factor should only be given in terms of midwinter peak, which, of course, would produce a closer relationship between the two, but I do not quite see why we should adopt that course, because we do not know this January what our midwinter peak is going to be next winter. In any case the maximum demand has little or nothing to do with the standing charges at the station. If we have a certain capacity of plant installed we must be prepared to run it. Therefore the whole of the losses in the station—and they are a very important standing charge indeed—are proportioned to the plant one is prepared to run. The losses from radiation boilers and steam pipes is one of the most important things a station engineer has to contend with. Mr. Kemp.

The CHAIRMAN (Mr. Chattock): I am sure we are all much interested in Mr. Taylor's suggestions with reference to a restricted hour supply, but, as has been pointed out, he has not shown us how to get that practically. On that point depends the real value of his paper, and I hope he will indicate in his reply how it can be done. The Chairman.

Mr. Taylor mentions that the restricted hour load must be restricted in two ways, that is, as regards time and quantity. The maximum must be restricted in order that in case it is developed too far it may not act in the other way and give us a peak load at times during the day and so exceed the evening peak due to the lighting. That seems to me a disadvantage in respect of the restricted hour supply, and I am afraid it will defeat its own end by not giving us the economy that Mr. Taylor expects. As to the advantage of a day load supply which Mr. Taylor assumes, it should be borne in mind that the day load supply, by rendering it possible to run the station more economically, helps the lighting consumers by bringing down the cost of supply at the station, and if the power supply were not superimposed upon the lighting supply, the charge to lighting consumers would have to be considerably higher. On that account I think that a proportionately greater benefit should be given to the power consumers than Mr. Taylor has assumed in his paper. The fact that in many stations power loads are now being supplied at somewhere about 1d. to 1½d. per unit, and that those stations have been able to reduce the cost of the current to lighting consumers, proves that the lighting consumer is really benefiting by the low charges made to power consumers. The more power consumers that can be attracted to the supply, the better it will be for the lighting consumers. I do not say the very low charges made in some undertakings that one occasionally hears about are always justified, but I think they can be justified in time. It all depends upon the nature of the load in that particular station and the amount of it. Of course one has to consider the conditions of all supplies when one is considering the charges to be made. I quite agree with Mr. Kemp that the definition of load factor has been very mixed up to the present. The definition in the *Electrical Times* has generally been accepted, but it is not really a workable load factor; it does not tell us what we really want to know in comparing one station with another.

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Mr. Holden. Mr. S. H. HOLDEN (*communicated*): Mr. Taylor refers to the restricted hour system of supply with its attendant disadvantages to the customer, but does not, however, mention the similar system based upon the use of a double tariff meter. These meters consist, as is well known, of an ordinary meter with two counting trains and a clock which brings one counting train into use at times of peak load, the remainder of the registration being upon the other counter. This system, of course, involves a little extra first cost at the meter, but this is insignificant in the case of installations of any magnitude, and will be certain to come down as the use of the system extends.

On its first adoption some difficulty was experienced with the clocks, but I believe that a quite reliable clock has now been on the market for some time. Quite a large number of station engineers are now adopting this system, and possibly some one may be able to speak from actual experience of its use. So far as I can gather its effect upon the load factor is practically the same as a rigidly restricted (but perhaps not rigidly enforced) hour supply, while it obviates any serious inconvenience to any individual customers on special occasions.

Mr. Wyllie. Mr. A. WYLLIE (*communicated*): The paper discusses the relationship between standing and running charges, and claims that the standing charges are much higher than is generally supposed. Mr. Taylor is also of the opinion that if a power load can be obtained to keep the plant fully at work during hours when it is not required for other purposes, a price may be charged for such power which need not include anything for standing charges, the lighting and traction loads bearing the whole of them.

This is the ideal power load which the author describes as "of moderate dimensions," "not unduly developed," and "restricted in amount." By these phrases he means a day load which would never exceed the maximum winter load for other purposes. If the power load was greater, for instance, than the evening load, according to the author it would need to bear some of the standing charges. The only way to obtain such a load is by restricting the hours of use or by the aid of storage, either in sub-stations or on individual consumers' premises.

Something might be said for the first case, which, however, the author dismisses "on account of the weakness of its financial aspect." For storage on consumers' premises, I doubt if anything at all can be said, on account of the complications, difficulties, inefficiency, and expense. The details of this scheme are not explained in the present paper.

I propose now to deal with some of the points in the paper in detail. The third definition on page 364 is confusing. The phrase "given out or absorbed" should be omitted. The supply station is only concerned with the energy delivered to the consumers' terminals, and the energy given out by the motor does not concern the question in any way. The definition should then read, "Consumers'

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load factor is the ratio of the average load to the maximum possible load." Mr. Wyllie.

Definition 4.—The definition of internal diversity factor needs alteration. The words "at any instant" should be omitted. There can be no question about the maximum loads on the consumers' premises at any instant, for at any moment they can have only one value, and the station load considered should be the actual maximum load and not the load at any particular moment. The definition would then read: "Diversity factor. This represents the number of times which the sum of all the maximum loads on consumers' premises exceeds the maximum load at the central station."

Definition 5.—Unrealised diversity factor. He says on page 379 that he has proved it correct by application to numerous instances throughout the country. I should therefore like to add a few words about it. The equation is the natural corollary of the definitions when corrected.

Let X be the average load on station.
„ Y be the maximum load on station.
„ Σ be the sum of consumers' maximum loads (what Mr. Taylor calls the maximum possible load).

$$\left(\text{The Consumers load factor} = \frac{X}{\Sigma}\right) \times \left(\text{Diversity factor} = \frac{\Sigma}{Y}\right) = \left(\text{Station load factor} = \frac{X}{Y}\right)$$

In the eariier paper Mr. Taylor repeats with some emphasis that the diversity factor is the reciprocal of the consumers' load factor. The above quotation shows clearly that this is not so except in the very special case when $X = Y$, that is, when the load on the station is quite uniform. The equation is of no use at all, and if an average value for the diversity factor is inserted, it is untrue. The coriection of the equation does not make the definition any more intelligible.

Mr. Taylor frequently uses the words "limiting" and "in the limit" in reference to the diversity factor. It is well known what these words mean when used in a strictly mathematical sense, but in Mr. Taylor's phraseology they seem to me to bear no satisfactory interpretation.

Mr. Taylor then discusses the division of the coal charge. He assumes that in a station of a given size each item of cost is made up of a fixed standing charge together with an additional charge which is strictly proportional to the output. No doubt this proposition is generally true, but it is impossible to establish the assumption so as to give it strict mathematical certainty.

In the diagram, Fig. 1, the word "average" should be struck out from "3,000 k.w., average load" on the horizontal axis. Mr. Taylor is not considering the case of a station running with an average load of 3,000 k.w., but, as he says on page 366, a station "running at the most economical load, *i.e.*, 3,000 k.w. maintained constant all through the twenty-four hours." 4 lbs. per unit is the coal consumption under

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Mr. Wyllie. these conditions. The ordinate therefore above 1,000 k.w., for example, ought to represent the coal consumption per unit for the same station running with a uniform load throughout the twenty-four hours of 1,000 k.w.

The division between the running and standing charges is quite arbitrary, although Mr. Taylor prefaces this investigation by the statement "the deductions that follow are financially safe."

The line C A, which is produced backwards on Fig. 2, Mr. Taylor says, cuts the vertical axis at £2,000. This is, as I stated, a pure assumption. The diagram in no way proves that that would represent the standing costs.

The solution of the problem given at the top of page 375 is wrong. Taking Mr. Taylor's conditions that

$$\frac{y}{z} = \frac{12\frac{1}{2}}{25} \quad \text{and} \quad \frac{z}{x} = \frac{12\frac{1}{2}}{30}$$

and substituting the values that these give for y and z in the equation we get as a result

$$x = 2{\cdot}658$$
$$y = 1{\cdot}329$$
$$z = 1{\cdot}107.$$

I would ask Mr. Taylor in his reply to show how he gets his values.

The same remark applies to the definition of the diversity improvement factor as to the definition of the unrealised diversity factor.

The object of my criticisms has been to point out what I consider the weakness of Mr. Taylor's methods. He undoubtedly has bestowed great pains and much thought on the preparation of it, but it none the less contains inaccuracies which I think ought not to be left unchallenged.

Mr. Pringle. Mr. P. J. PRINGLE (*communicated*): Mr. Taylor's paper has raised some very interesting points, and to some extent I agree with him in his warnings as to whether the low figures at which we are now selling power are really remunerative or not. I do contend that in fairness to both classes of consumers, that is, lighting and power, that the latter should bear their fair proportion of the whole capital charges.

If some fresh power business requires an extension of plant, then to estimate the capital charges purely on this outlay is not sufficient. Many of us will find that in a few years our lighting business will be secondary to the power supply business, and extensions of engine house, boiler house, and mains and feeders will be directly required for this class of load.

I am a strong believer in the supply of power on the restricted hour basis, and I have within the last year been pushing this very strongly in Burton-on-Trent. Mr. Taylor refers to the serious limitations owing to day fogs as well as to the drawbacks from the consumers' point of view. I admit both these points, but I am confident that there are few towns where it is not possible to obtain a certain amount

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of power on the restricted hour basis. In Burton-on-Trent the restricted hour supply system was introduced last summer, and all power taken on this basis is supplied at a 1d. per unit with reductions as low as ¾d. per unit in the case of very large quantities. Our unrestricted power supply prices are 3d. per unit for first 1½ hours on the maximum demand system and 1d. afterwards, or an alternative rate of 2d. first 10,000 units per annum and 1¼d. afterwards. In the case of very short hour consumers they cannot get below 2d., and good regular load full working hour customers do not get below 1d. Mr. Pringle.

The restricted hour system therefore offers to our very best customers about 33 per cent. reduction in their bill, and to shorter hour consumers considerably more. Three of our largest consumers, having between them twenty motors with a total of 167½ H.P., decided a short time ago to change over to the restricted hour supply system, and, in addition, we have attracted a number of new consumers with these low rates whom we should probably have not obtained otherwise. In the case of these three consumers who changed over, they have altered their hours of work so as to coincide with the restricted hours.

We have also accepted a good deal of power load for refrigerating plant purposes on the understanding that such power will not be supplied after a certain date in autumn, and thus prevent it overlapping our lighting loads and increasing our yearly peak load. The nett result of the introduction of this system is that, to date, we have out of 472 H.P. connected, 261 H.P. on the restricted hour basis, and we have orders on hand for a further 116 H.P. on this system, bringing this up to 377 H.P. out of a grand total of 588 H.P.

This financial year we have approximately received some £750 revenue from consumers actually connected on the restricted hour system, and next year, including the applications in hand, we shall get approximately an additional £1,000 on this account. The whole of this revenue is of course earned without it being necessary to allocate any capital charges at the station or on our general system of mains, and there is no doubt that in our case capital expenditure for future extensions will be postponed for a considerable period.

Another effect of changing over existing consumers on to the restricted hour system is that this year our maximum load has only increased very slightly on last year, a little under 5 per cent., notwithstanding the fact that this year our motor connections have increased some 240 H.P. In addition, our output for motor units will have increased some 155 per cent., and our combined load factor for lighting and motor supply improved nearly 25 per cent.

I would certainly recommend that more consideration be given to this system of supply for power, as it will be found distinctly more profitable than the ordinary form of power supply, and in addition a safe one, as the actual costs can be calculated to a very close degree.

Mr. E. M. HOLLINGSWORTH (*communicated*): The subject of Mr. Taylor's paper is of great interest to all central station engineers. Mr. Hollingsworth.

With an average combined load factor of 45 per cent., the coal con-

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Mr. Hollingsworth. sumption of 4·7 lbs. per unit generated at St. Helens (lighting power, and traction; slack at 6s. 9d. per ton) agrees very closely with that point on the coal diagram, Fig. 1, which represents the weight of coal for a similar load factor.

I am afraid many central station engineers must give up all hopes of obtaining a large power load if the price to be charged per unit is arrived at on the lines laid down in the paper. Mr. Taylor compares the actual charge per unit for traction at Liverpool with his calculated figure (page 375). It would be of still greater interest to know how the average price obtained for power in that city compares with the figure of 1·57d.

With regard to the restricted hour supply I have no doubt that in connection with a few industries such a system may be found satisfactory, but manufacturers generally will not agree to restrictions and complications, and I do not blame them. Storage batteries on consumers' premises would certainly be a means of greatly improving the station load factor and also ensuring better voltage regulation (very necessary in some towns having a considerable motor load), but by adopting such a system the central station engineer will run considerable risk of losing some consumers altogether. A consumer having installed a battery will more readily be persuaded, say by the gas representative, to take another step and put down the rest of the plant necessary to generate his own current.

It is all very well calculating the price that should be charged per unit, but when all is said and done we must either decide to leave the power supply alone or adopt such rates that will enable electricity to compete economically with other forms of energy. With a total works cost not exceeding 1d. per unit, it is in my opinion commercially possible to supply large consumers of energy for power at less than 1d. per unit. As the motor load develops it will undoubtedly overlap the lighting load to a greater or lesser extent, depending upon local conditions, but the revenue obtained from the new business will more than compensate for any additional capital and other charges that may become necessary.

Mr. Morcom. Mr. R. K. Morcom (*communicated*): There are always two sides to a bargain, and Mr. Taylor speaks as a seller. There is a great tendency on the part of the suppliers of electricity to try and make their load suit their plant, and naturally, because it is cheaper to do this than to get a plant to suit their load. Hence various suggestions of battery substations, batteries on consumers' premises, restricted hour clauses, and the like.

Now two questions are always suggested by a paper like this. (1) Under what conditions can one generate for one's self more cheaply than one can buy electricity. (2) Are some of the very low power charges of recent date financially sound.

In considering question (1), the magnitude and nature of the load, the site of the factory, and the nature of the product are important factors. If the load of a factory is of a constant and fairly steady

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character, it is generally possible to arrange the units so as to give, with an overall load factor of 25 per cent., a running plant load factor of from 50 per cent. to 75 per cent., and also effect a considerable saving in standby losses, etc., by always working definite hours. Mr. Morcom.

A station supplying a quarter of a million units on a running plant factor of 60 per cent. can generate at a works cost of 0·4d. and a total cost of 0·8d., and one supplying one million units under similar conditions at 0·3d. and 0·6d., and so on, figures which would leave very little profit for an outside supply.

The lowest figures would probably be obtained by engineering factories, especially those connected with electrical engineering, because the repair bills would be lower, and the staff can be reduced to a minimum.

Considering question (2), we will assume a well-designed private supply with modern engines running on a good vacuum and with high-pressure superheated steam. Suppose it is fitted with, say, two 250-k.w. and one 150-k.w. sets, and turns out one million units on a 60 per cent. running plant load factor. The fuel per unit will be within 10 per cent. of a first-class public supply's figure, and very likely be better by reason of the power of adaptability of a private supply. The extra wages for a private supply is a small item on a million unit output, and will be compensated for by the reduction of staff charges. Generation dead charges would be low on the good load factor presupposed. In such a case, if a public supplier quotes below the figure at which the internal station can supply it is almost inconceivable that it can pay for the mains and make a profit.

In fact, in such cases it would probably be more profitable for the company or the municipal authority to buy up their prospective consumers' private supply station and run it as a sub-station, a proceeding just as sensible as the supply at some of the prices quoted nowadays.

Mr. A. M. TAYLOR (*in reply*): Several speakers have misunderstood a paragraph in my paper to mean that the figure arrived at for Liverpool was that which I considered the lowest obtainable for the standing charge for motive power supply. I wish to disclaim any such intention. Mr Taylor.

As stated on page 382, I consider that ¾d. per unit is about the lowest value for the standing charge for this class of supply, if we take values of station load factor for towns having large and consequently typical motor loads, rather than values which only obtain in certain specially favourable localities. The figures given for Liverpool are merely introduced to show the effect of dividing up the standing charges. The figures are not up-to-date, and may have greatly improved since I received them.

In reply to Mr. Shawfield, I quite agree as to the correctness—perhaps I should rather say advisability—of debiting the ordinary "interest-paying" motor load with those items of *additional* expense incurred by it, and none other. I do not, however, agree that it is possible to supply, under the conditions he postulates, 2,000,000 units

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Mr. Taylor. at 0·6d. unless the works considered is one of many such in the district, which is unlikely, considering the population. Mr. Shawfield contends that the new station for power will *cost* much less than the existing lighting station of 2,000-k.w. capacity. The population he indicates, however, precludes our putting down a station for an ultimate capacity of over 10,000 k.w., and it would be unwise to put down more than 3,000 k.w. to begin with.

I happen to be in possession of a careful estimate for such a station based upon actual designs and quotations. The capital cost of the initial equipment works out at £40 per kilowatt of plant capacity and of the final equipment at £30 per kilowatt. On such a scheme the maximum demand would probably average only two-thirds of the plant capacity. Hence the capital cost of the initial equipment would be £60 per kilowatt of maximum demand. Let us, however, put it at £50 per kilowatt. At 6 per cent. for interest and sinking fund this amounts to a standing charge of £3 per kilowatt of maximum demand per annum; which, on a load factor of 30 per cent., represents a charge per unit of 0·27 as shown in Fig. B, where interest charges are plotted below the datum line. To this we have to add costs of distribution. The standing charges on this account for one station with which I am acquainted, supplying 10,000 H.P., are as high as £3 per kilowatt of maximum demand per annum, while the average of twenty-six London stations is, I understand, about £4 per kilowatt. Again favouring Mr. Shawfield let us put it at £2 10s. per kilowatt of maximum demand per annum. This gives on a 30 per cent. load factor, 0·22d. per unit for distribution, as per Fig. B.

Mr. Shawfield's next point is that the cost of the *additional* wages, rent, rates, taxes, maintenance, etc., will be less than the existing costs. Where there is a change in the dimensions of the station of the radical nature indicated, I cannot agree with Mr. Shawfield. If he will take the figures for the six largest municipal stations he will obtain an average standing charge for these items (exclusive coal) of £2·60 per kilowatt of plant capacity per annum, as against the average of six very much smaller stations, of the size of Wolverhampton, which works out to £2·62 per kilowatt per annum, showing that mere size does not reduce these items to the extent that might be expected, the aggregate capacity of the six larger stations being seven times that of the others.

Taking this standing charge at £2 per kilowatt of plant, we have £3 as the standing charge per kilowatt of maximum demand per annum, or 0·27d. per unit for a 30 per cent. load factor.

We now have a total of $0·27 + 0·22 + 0·27 = 0·76$d. per unit; so we must evidently not allow anything for net profit (*alias* "reserve fund"); and finish up our total by adding 0·20d. for coal and petty stores. Total = 0·96d. per unit.

Mr. Shawfield may reply, "Yes, but the consumer I am considering brings in a load which has a load factor of 40 per cent., corresponding with 3,200 units per annum per B.H.P. installed." But such a consumer would not, by the addition of *his* load alone, improve the

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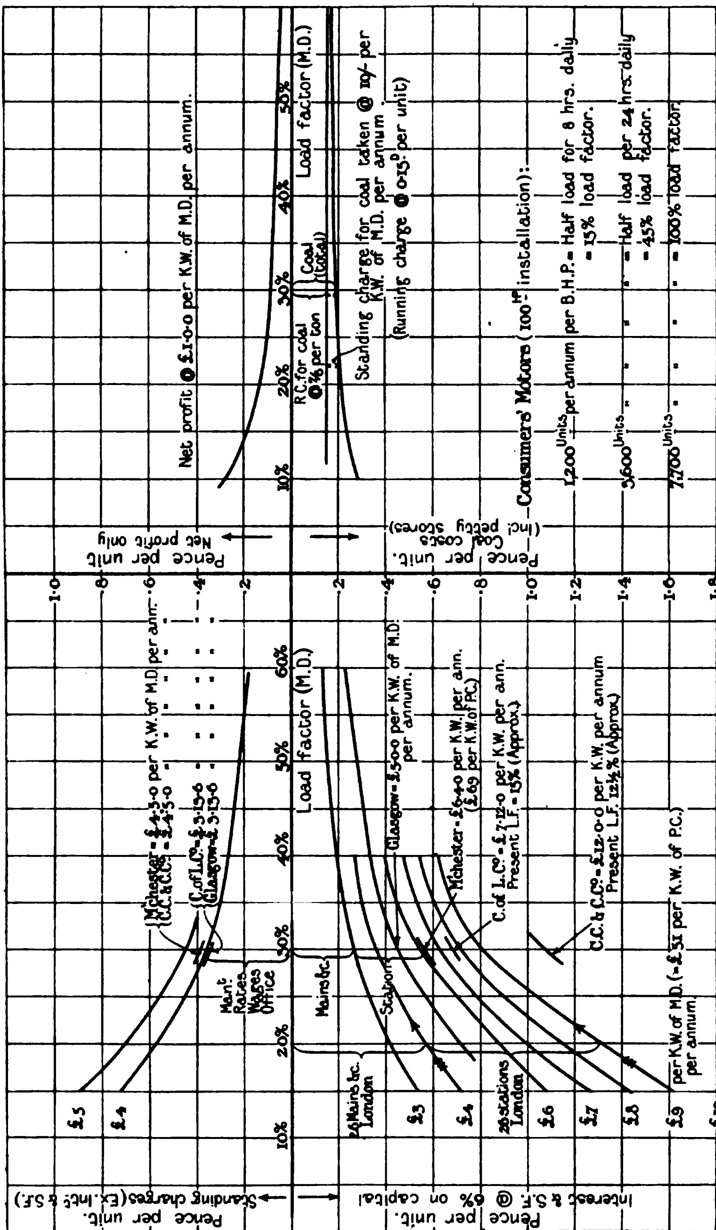

Note.—"P.C." = Plant capacity.
"M.D." = Maximum demand.

FIG. B.

Mr. Taylor. station load factor by more than perhaps 2 or 3 per cent. If the accession of this customer would induce other large customers to come on, the load factor of the motor load might go up to perhaps 36 or 37 per cent.

A station load factor of 30 per cent. for motor load is a good 10 per cent. above the average obtained in the largest stations in this country, as Table III. will demonstrate. Still, in certain favourable localities where good all-night loads are obtainable and there is no "unrealised" diversity factor, a station load factor of 40 per cent. might be realised, as shown in the left-hand bottom figures of Fig. C.

TABLE III.

B.H.P. Connected.	Units sold per Annum.	Units per B.H.P. per Annum.	Consumers' Load Factor.	Observed Maximum Demand.	Diversity Factor.	Station Load Factor calculated from Observed Demand
			Per Cent.	K.w.		Per Cent.
3,590	2,183,000	610	7⅛	830	4·3	30
9,400	4,000,000	425	5⅛	3,500	2·3	13
9,800	4,750,000	485	6	3,300	2·5	16·5
4,000	1,360,000	340	4¼	500	6·8	31
3,900	1,940,000	500	6¼	1,100	3·0	20
1,600	1,060,000	660	8¼	600	2·3	20
630	504,000	800	10	200	2·7	29
H.P. 32,920	15,797,000	H.P. 480 (average)	6 (average)	10,030	2·8 (average)	18 (average)
9,800	—	—	—	—	—	12½ (less than)
8,000	—	—	—	—	—	15
50,720	—	—	—	—	—	16

If we then take a 40 per cent. load factor the standing costs would come out at 0·57d., to which adding the running cost at 0·20d., we get a total of 0·77d. per unit. I therefore maintain that, granting all Mr. Shawfield's premises, and waiving any charge for reserve fund it is to me inexplicable how he can supply at less than 0·8d. per unit, even to a consumer of the class indicated.

Again I would repeat that, with the battery scheme it is not only possible to supply to such a consumer at 0·6d. per unit, but it is possible for a station having only a 20 per cent. load factor to put by a reserve fund, for each such consumer obtained, amounting to the best part of £1,000 per annum.

I trust it will be apparent from the above that, far from looking at the obtaining of motor loads from a pessimistic point of view, I am

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doing what I can to improve our opportunities in this respect; always, however, with the proviso that the finances of the station be not more **Mr. Taylor.**

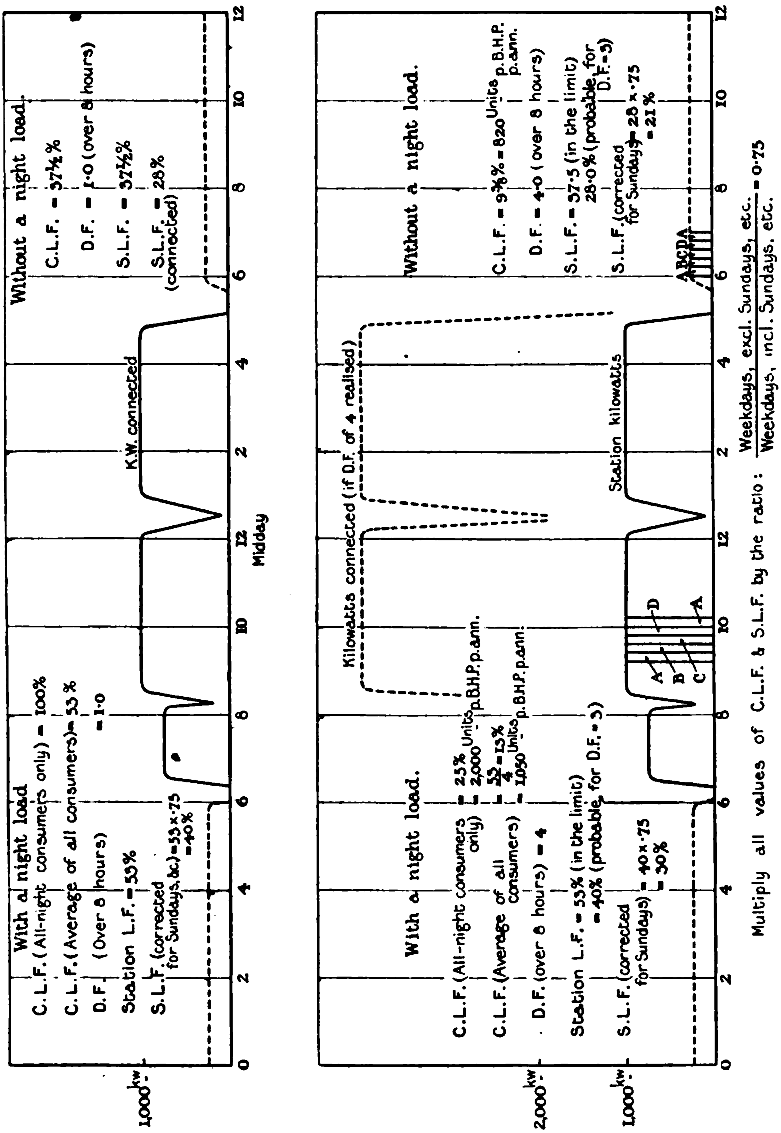

FIG. C.

heavily mortgaged to the motor load than will be capable of realisation when the latter has had fair opportunities of development.

Mr. Chattock's contribution to the discussion introduces another

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Mr. Taylor. aspect of the case. He virtually says that, since the lighting load is benefiting and will benefit so largely by the motor load, it is only fair that every benefit possible should be conferred on the latter to enable it to establish itself; as otherwise it might be a case of "killing the goose that lays the golden eggs!" This remark applies, I think, very forcibly to the item of reserve fund.

Mr. Lackie indicates how they have, in Glasgow, put net profit to reserve fund, and again used this to write off depreciation and sinking fund, with the very desirable result of reducing the capital on which interest has to be paid. It would seem that, since the capital spent on the lighting load has, in the past, been out of all proportion to the kilowatts of demand, it is eminently fair to handicap only the lighting load with a reserve fund charge, as proposed by Mr. Chattock.

To what extent Mr. Lackie may be carrying this out, I do not know; he cannot have much margin for net profit in his present *power* prices at Glasgow.

He rightly objects to the high rates I have taken for power, in the illustration of the effect of internal diversity factor in *not* reducing the charges for a power load. The figures given were, however, substantially those per station kilowatt for Wolverhampton, two years ago. The fixed charge of £7 19s. to which he objects corresponds with the charge of £4 5s. per kilowatt per annum plotted above the datum line in Fig. B, and, moreover, included a standing charge for coal.

With regard to the charges debitable to the *ideal load*. Let us assume that a group of large manufacturers using, say, 5,000 H.P., were to offer to take electric power for the whole of their work, demanding this power only after midnight (*i.e.*, putting down and maintaining their own accumulators), if in return they could obtain such power at the bare running expense, deduced as per my paper as regards coal, wages, repairs, etc., *plus*, say, £2,500 per annum for net profit, would it not be advantageous to close with such an offer; especially as it would add 5,000 H.P. to existing connections and probably materially improving the load factor of the station? Or would it be better to lay down new plant and mains and just succeed—perhaps not even this—in repaying interest on capital borrowed without a penny to put by for reserve fund or to reduce the lighting rates of charge?

The extra cost for current, on the terms of the manufacturer's offer, *involves no speculation whatever* on the part of the supply company, however poor a load factor the load may prove to have.

In this connection I think it is a strong argument for exceedingly low terms for "non-peak" loads that the Tynemouth Corporation has accepted an offer from the Newcastle Electric Supply Co. to supply them with current at non-peak hours at the low figure of 0·38d. per unit. The Corporation have to generate their own current during peak hours. Similarly the London County Council proposed to supply current to the London municipalities at non-peak hours, at a price which would be equivalent to about 0·35d. per unit. But for the

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high price of coal in London this would, of course, have been much lower. Mr. Taylor.

As regards repairs, the sentence in my paper (page 372) referred to was badly expressed. It should have read: "We have left for further consideration the repairs on a *proportion* of the plant only, representing in capital outlay about one-third of the whole plant."

Mr. Fedden asks about space required for accumulators. I may say that a room 14 ft. × 9 ft. will accommodate cells for an installation of 100 H.P. Also the estimates from which my curves of expenses are taken include an allowance in the way of pecuniary compensation for floor space occupied.

As regards maintenance, this is to some extent dependent on capital cost, and on number and size of cells. The small cells hitherto necessary for supplying a 20-H.P. motor would cost 80 per cent. more per kilowatt than the large cells which I propose. The number of cells is about $\frac{1}{10}$th of that hitherto considered necessary. I am not prepared at the present time to disclose my proposals for maintaining these cells; but it may astonish some of my critics to know that I could replate the whole of the batteries (on both poles) every three years for another 0·05d. per unit. As they would be inspected once every fortnight by an expert, it seems incredible that they should not last longer than three years.

Mr. Vignoles instances a flour mill which he could supply at 0·5d. having an "absolutely steady" 24-hour load. If he applies the principles which I have instanced in my reply to Mr. Shawfield, I think he will still find difficulty in coming below say 0·7d. per unit, as unless his station is a very small one, that one mill will not raise his station load factor above 40–50 per cent., and if his station is a very small one, he cannot possibly construct it for the capital costs I have allowed to the case cited by Mr. Shawfield.

Mr. Vignoles asks: "Why not put the batteries into sub-stations?" I know of no reason whatever why they should not be successfully introduced into sub-stations, wherever the standing charges on supply exceed 1¼d. per unit. But in those same towns, my scheme would permit of great reductions in the cost of power, while the sub-station scheme could only *begin* to show reductions over existing supply when the existing costs were over ¾d. to 1d. per unit.

An example will make this clear. The sub-station battery, having to deal with a peak of five hours' duration (from root to root), costs about £19 per kilowatt which, at 6 per cent. interest and sinking fund and with a 15 per cent. load factor, works out to about 0·24d. per unit received from busbars. But in a rapidly developing scheme, the capacity installed in the main station or sub-station is often some 50 per cent. in excess of the maximum demand, hence the value of 0·24d. is raised to 0·36d. per unit.

Add another 0·36d. for maintenance of cells as contracted for with the storage company and we get 0·72d. per unit received from bus-

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Mr. Taylor. bars. Add 20 per cent. for energy lost in booster and in cells, and we get 0·86d. for every effective unit supplied to feeders.

Add interest, etc., charges on low-tension feeders and distributors; and we get, for 15 per cent. load factor, a total of 1·16d. per effective unit delivered to consumer's premises, as taking the place of the whole of the existing standing charges of the supply. Where the peak was of less than five hours' duration of course better results would be obtained.

Mr. Bowden's remarks are vitiated by the fact that he is talking about "running plant load factor," while I am talking about total "plant load factor." Consequently, he considers only the losses which occur in the engines, and ignores those that take place in the boilers and steam ranges. I agree with Mr. Kemp that these latter are the most important, and that they vary more nearly in proportion to the total "plant load factor" than to anything else. The plant load factor is always less than the maximum demand load factor (station load factor) and never reaches anything like the figure of 80 per cent. quoted by Mr. Bowden.

Mr. Jeckell suggests that my figure of 25 lbs. per unit for the engine steam consumption is too good for anything but recent years. I may say that nine years ago, I had an offer from Messrs. Belliss for a 400-k.w. set having a guaranteed steam consumption of 22·5 lbs. per kilowatt and a 200-k.w. set having a consumption of 24·7 lbs.

I cannot agree with him that every expense incurred for repairs is a running charge. The point under consideration is the difference in repairs costs between a plant running on a 12½ per cent. (lighting) maximum demand load factor, and the same plant employed for a purely motor load having a 25 per cent. maximum demand load factor.

Taking the boilers first, the standing charges on account of losses in radiation and steam ranges amount, at the load factor considered, to an equal quantity with the running charge (see Fig. 1). The generation of twice as many units will therefore only involve the passage of about 50 per cent. more water and coal through the boilers. It is inconceivable to me that renewal of boiler tubes and firebars will cost more than, say, 1½ times what they did on the smaller load factor; especially as there is no unexpected sudden demand with a motor load, requiring forcing of the boilers. Then, as regards the costs of the engine-room repairs, if Mr. Jeckell will prepare a statement showing the number of piston rings, glands, brasses, commutators, etc., worn out by pure wear during the last few years, and their money value, and show that this works out, taken over the total number of units generated during these years, at anything approaching, say, 0·1d. per unit—a common enough figure for engine-room repairs—I will give up my contention.

It will be seen from Fig. B that, on a plant of a capacity such as that at Coventry, and with a 25 per cent. load factor, a charge of 0·05d. per unit will account for virtually £500 per annum. Supposing that the parts named lasted, on the average (taken over the whole station),

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for only five years there would be a sum of £2,500 available for replacing them; and if they lasted ten years, a sum of £5,000. It should be mentioned that, in taking ⅓th of the total cost of repairs (as usually ascertained), I am deducting entirely the repairs on mains and feeders, etc., which are a standing charge, and often quite a large proportion of the whole item for repairs. Mr. Taylor.

Mr. Hollingsworth suggests that, by adopting the system of accumulators on consumers' premises, they would run a risk of losing some customers altogether. In reply, I would say that, even if the consumers supplied their own cells, the gain of new consumers by reduced prices would so greatly outweigh the risk as to make it a negligible factor. On the scheme, however, which I am proposing the risk alluded to would be virtually eliminated altogether. The objection he raises as to space I have already answered in my reply to Mr. Fedden.

Mr. Pringle's remarks are most interesting to me, as an advocate of the system he recommends, and they are a proof that, in certain small towns, the restricted hour system offers great possibilities; and there is no doubt that, at ¾d. per unit, it ought to pay well. It must not, however, be overlooked that the price must cover a proportion of interest and sinking fund charges, of the nature of a reserve fund, to meet the possibility of the creation of a "day" peak—a possibility which may be nearer than Mr. Pringle thinks, if they suffer at all from fogs in Burton.

It will be interesting to see how the restricted-hour system succeeds in Bradford, where it is, I believe, about to be given a trial.

Mr. Kemp's remarks as to the definition of load factor demand our careful consideration. There are two distinct points of view of this question, and Colonel Crompton enunciated both definitions of load factor in the paper to which Mr. Kemp referred. The maximum demand load factor is most valuable, and in fact absolutely essential, when we are distinguishing the characteristics of one class of load entering the station from those of another class. It determines, when taken in conjunction with the combined diversity factor, the true allotment of standing charges to lighting, motor, or traction load. But, as Mr. Kemp says, for a true gauge of the economy of the plant in the station, including boilers and steam ranges, the (total) plant load factor is the best criterion. The so-called "running plant" load factor is principally useful as an index to engine efficiency.

It is a question whether the maximum demand load factor, as it so greatly governs the costs of distribution, may not be found to be, in the future, of more importance than the "plant load factor"; but in any case annual results established for the one are transferred most easily into terms of the other, when the ratio of maximum demand to total plant capacity (obtainable from the *Electrical Times* table of costs) is known. I fully agree with Mr. Kemp about the maximum demand load factor being no true index of station economy, and that the plant load factor is such an index.

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Mr. Taylor. Perhaps a committee of nomenclature of the Institution will settle the matter for us as to which, if either, of the competing load factors has the right to be called the "true" load factor.

Mr. Kemp's valuable contribution as to the cost of restricted-hour supply, obtained by actual experience with a concrete case under conditions precisely similar to those embodied in my suggestions for accumulators on consumers' premises, is one of the strongest arguments that can be adduced for conclusion No. 1 of my paper. Indeed, it is 25 per cent. better than the lowest figure (0·2d.) I there put forward.

In this connection I may say that Mr. Shawfield, who has given this matter as much attention as most people, put his running costs for Wolverhampton as low as $\frac{1}{4}$d. per unit two years ago, classing all other charges as standing charges. Mr. Kilgour has also estimated the "running charge" at as low a figure as $\frac{1}{8}$d. for a moderate-sized station, based upon a figure of $\frac{1}{4}$d. per unit obtained at Cheltenham.

As regards the details of my scheme for which Mr. Kemp asks, it is impossible to give these in a few words. I may, however, explain that in the case, for instance, of a 200-H.P. installation having a 15 per cent. load factor, I would provide a 100-k.w. (to 120-k.w.) motor-generator, wound for 440 volts on one side and, say, 50 volts on the other side. During the times of peak load this motor-generator would be connected to the motor circuit, its low-voltage side being connected with some 28 very large accumulator cells (charged during the previous night). A time switch acts, through a relay, on the field rheostats of the two fields causing the cells to take up the motor load through the intermediary of the motor-generator. The circuit which is supplied by the latter is then automatically disconnected from the town's mains, and the cells continue to take the load till closing time.

By using these large cells the capital cost per kilowatt is very much less than with the 230 or more cells that would otherwise be necessary; and, partly on this account and partly because of the fewer and larger cells, the maintenance costs come down rapidly. With small installations the effect is still more marked. On a 200-H.P. installation, with a 15 per cent. consumers' load factor, the units brought from the town's mains are 270,000, and the units delivered to the small motors are 240,000. This comparatively high efficiency (87 per cent.) is owing to the fact that only about $\frac{1}{18}$th of the total energy sold is put into the cells, the small motors being supplied direct off the town's mains during the rest of the year. The cells occupy a space 28 ft. by 9 ft. or 14 ft. by 18 ft., which can be subdivided if wanted, and the motor-generator occupies a space of only 10 ft. by 4 ft.

Mr. Wyllie finds fault with my methods, definitions, suggestions, and conclusions. His statement that $\frac{X}{\Sigma}$ represents the consumers' load factor appears to be a "pure assumption." The other two terms in his equation I do not dispute; but when he goes on to say that

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the equation "proves" that the diversity factor is only the reciprocal of the consumers' load factor in the case of a 100 per cent. load factor at the station, I beg leave to differ. It is quite easy to conceive two cases occurring, one in the forenoon and one in the afternoon of the same day, where the station load factor (taken in each case over a given period of four hours) is, in the afternoon, double what it was in the morning, the consumers' load factor being constant but the diversity factor being doubled; that is, the product of the diversity factor and the consumers' load factor is, in each case, equal to the station load factor, in spite of the fact that the ratio of X to Y has altered. Mr. Taylor.

The best answer to Mr. Wyllie is to refer him to Table III., where he will find a record of actual facts, as nearly as I have been able, through the kindness of several station engineers, to obtain them. Allowing for the night loads (which, of course, disturb the simplicity of my equation), there is shown to be not only a diversity factor—which Mr. Wyllie seems to doubt—of greatly varying value, but one that *does* approximately vary in an inverse ratio to the consumers' load factor.

Mr. Morcom's estimates do not tally with results which, I understand, have been obtained in Messrs. Belliss's own works, and they are pitched for a size of installation which is decidedly above the average in both size and load factor. He does not produce any details of his estimates, as I have done for the central station, nor state what proportion of spare plant he has allowed, nor the cost on a small installation of the skilled attention which is to produce better results than in the works of the makers of the engines, nor the cost of the floor space required, nor whether he includes lighting, etc., and without such figures criticism is not possible.

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MANCHESTER LOCAL SECTION.

SOME NEW FLYWHEEL STORAGE SYSTEMS.

By A. P. WOOD, Member.

(*Paper read, February* 19, 1907.)

The subject of electric winding is one which has had a considerable amount of attention during the last few years from electrical engineers. There were several papers read on this subject last year before the Institution, but they were principally on the question of electric *v.* steam winding. I do not propose to go into the merits of the two systems to-night, but I think it was agreed that electric winding could not be commercially practicable unless in such cases where the coal used at the pit exceeded in value 2s. 6d. to 3s. per ton. The fact remains that a considerable number of electric winders are being installed in this country at the present time, and the practical results attendant on these installations will be, of course, the best warrant as to their merit.

I therefore propose to describe a few patents which have been taken out during the past year, and are the property of my company. These patents comprise both 3-phase winding and continuous-current winding; the former have been taken out by Mr. McLeod and myself, and the latter by Mr. Kelsall, Mr. Warburton, and myself.

Now, what are the principal requirements of electric main winding plants?

(1) Cheap first cost.
(2) Low coal costs.
(3) Ability to run the main motor in case the flywheel storage system fails.
(4) Ease of control and simplicity.
(5) Desirability of running the winding motor at nights for lifting water, etc., without the use of the flywheel set (the winds in this case are generally about 1 per 20 minutes).

The requirements of electric winding are, of course, very severe, and this is best shown by the diagram, Fig. 1, showing the power required during a complete wind, the maximum horse-power during accleration being 2,000 H.P and the average demand being about 800 H.P.

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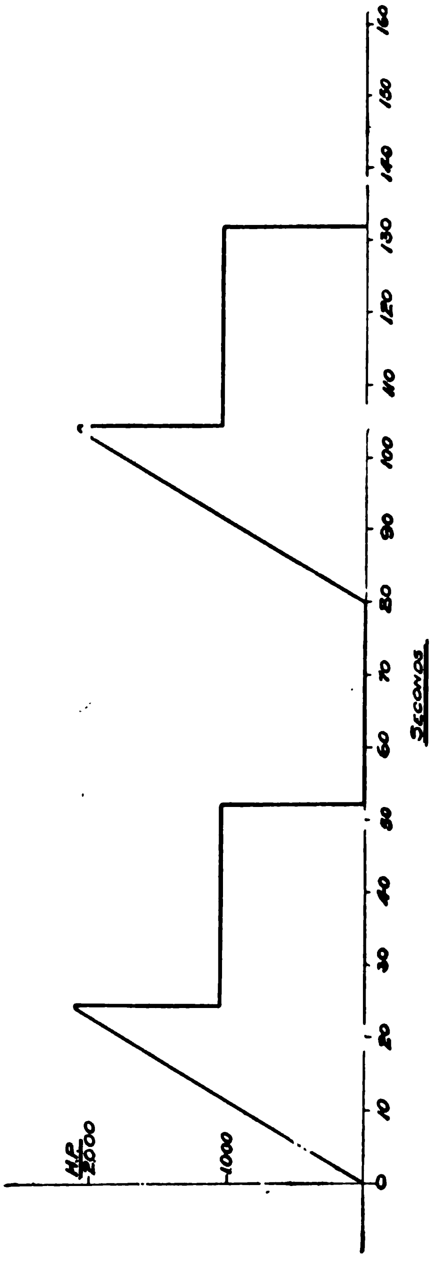
H.P.
2000
1000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Seconds

FIG. 1.

Three-phase Systems.—The system best known in this country and abroad is the Ilgner, but this is not a true 3-phase system, as it is necessary to convert to continuous current, using continuous-current motors on the main winding gear.

This system has been so fully described before that I do not think it necessary to go into details.

It consists, briefly, of a flywheel system, consisting of a 3-phase induction motor coupled to a continuous-current generator. The latter drives a continuous-current motor geared, or direct coupled, to

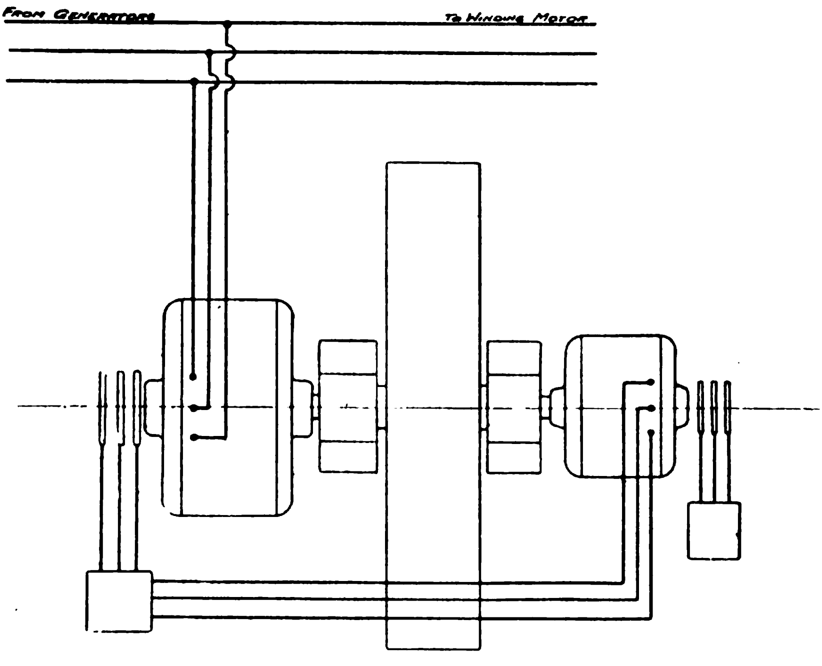

FIG. 2.

the main winding gear, the control of the main winding motor being effected by the well-known Ward-Leonard system.

The three-phase motor is fitted with slip rings so that resistance can be introduced when required. Of course, the flywheel cannot give out, or store, energy unless the speed is varied, and, therefore, it is necessary to introduce resistance into the rotor circuit when it is desired to make the flywheel give out energy; and to speed the flywheel set up again this resistance is necessarily cut out.

The main winding gear, therefore, is absolutely dependent on this flywheel system, and should the latter break down in any way, the winding gear cannot be used.

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Of course it is necessarily an expensive gear, and to duplicate the flywheel system would add so much to the cost as to make it practically prohibitive, unless the value of the coal burnt at the pit-mouth was very high.

I have, therefore, thought it most desirable that the winding motor should be 3-phase, and so arranged that it could be worked in case of failure of the flywheel system. With this object in view, therefore, in conjunction with Mr. McLeod, I worked out a series of systems, and made a considerable number of experiments with the same.

Of course it is well known that the Westinghouse Company have a system which is known as the rotary-converter system, and this has been fully described by Mr. Braun at the discussion on Mr. Mountain's paper. This system has the advantage over the Ilgner that the winding gear can be worked if the flywheel system breaks down.

The first system to describe is called the Cascade Flywheel Storage System (see Fig. 2). This consists of two 3-phase machines coupled together in cascade, and attached to a flywheel, the main winding motor being 3-phase.

The flywheel set is started up in the usual way by resistance in the rotor circuit of the second machine; the latter is afterwards cut out, the speed of the flywheel rising in proportion. Assuming for a moment that we have a 4-pole and 2-pole machine in cascade, then if the second machine is in circuit, the speed of the set will correspond to that of a 6-pole machine, and if the second machine is cut out, the speed will correspond to a 4-pole machine. Assuming for a moment that 50 periods is used, this will give, say, 1,000 and 1,500 revolutions per minute respectively. Assuming that the flywheel set is running with the second machine cut out, the main winding motor is then started up by resistance in the rotor (preferably a liquid resistance tank controlled by a valve allowing the liquid to pass to the resistance box from a tank overhead, fed by a small centrifugal pump). Simultaneously with the starting up of the main motor, the second machine of the cascade is put into service, and the flywheel begins to reduce its speed, the cascade system delivering current back to the mains and assisting the main supply until the speed attains synchronism, corresponding to 6 poles, *i.e.*, 1,000 revolutions per minute.

It is, of course, well known that an induction motor, when running over synchronism, will deliver current back to the supply. This property is utilised in mountain railways when the cars are descending the hills.

As soon as, or before, the current from the main winding motor is shut off, a bar is put across the three wires forming the connections between the two machines in cascade, and the flywheel begins to absorb energy and speed up to 1,500 revolutions per minute. It is then prepared to discharge itself as soon as the main winding motor is started up again. The operations of the motor during the ordinary working day are almost perfectly regular in time of stoppages, etc., for loading

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and unloading, and the energy required to be stored up in the flywheel can be calculated to the greatest nicety.

The disadvantage of this system is the poor power factor (see Fig. 3), as the main generator has to supply the magnetising current for the flywheel set under all conditions.

The following are a few readings observed on a small cascade fly-

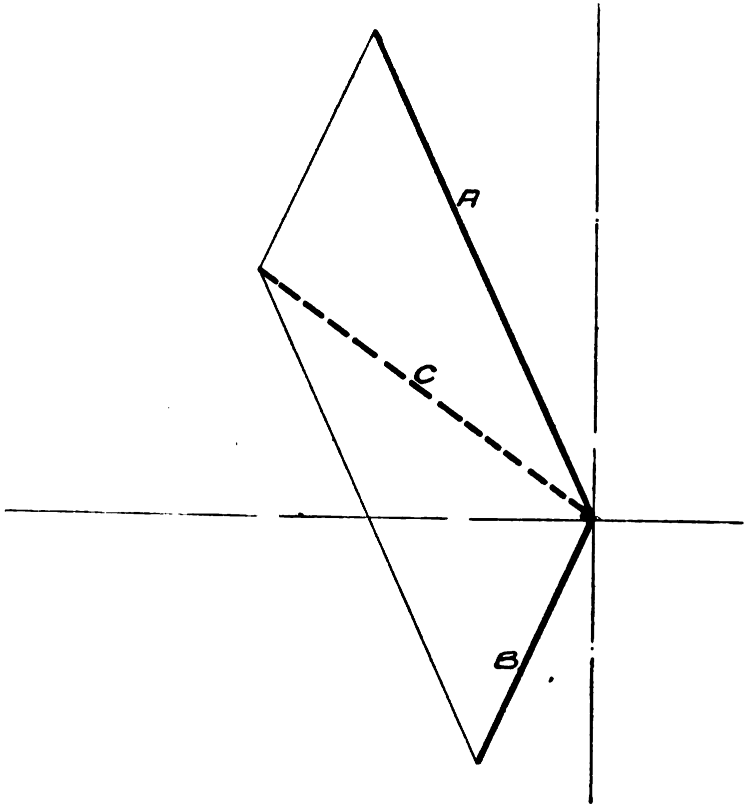

FIG. 3.

A. Winding Motor	100 Amps. Cos θ = 0·9
B. Flywheel Cascade System Generating	50 Amps. Cos θ = 0·9
C. Current required from Mains ...	78 Amps. Cos θ = 0·58

wheel set, showing principally the poor power factor obtained when the flywheel set is delivering energy back to the mains.

Readings taken on cascade set flywheel discharging—

Power factor winding motor about 0·9 at 15 amps.
Power factor cascade set about ... 0·93 at 8 amps.
0·83 at 15 amps.

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Winding Motor Amps.	Flywheel Set Amps.	Difference Amps.	Actual Current supplied by 3-Phase Generator Amps.
15·3	8·7	6·6	11·8
15·0	15·5	−0·5	15·2
14·5	6·2	8·3	11·4

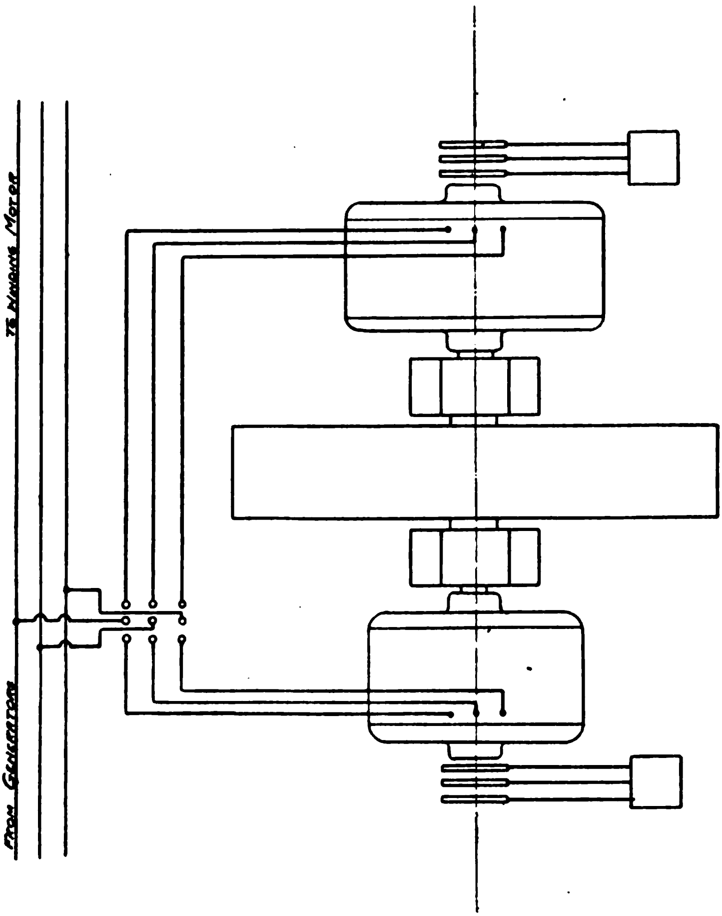

Fig. 4.

The second set of readings show practically equal currents on the generator main winding motor and flywheel set, the power factor on the generator in this case being 0·03. The third set of readings show a power factor of 0·64 on the generator. I do not think that power-supply companies would quite appreciate loads with power factors in the neighbourhood of, say, 0·5 as an average.

The second system which I propose to describe consists of two

induction motors, say, a 4-pole and 6-pole, coupled together with a flywheel between (see Fig. 4). These two machines are not in cascade, but a throw-over switch is arranged so as to connect either one machine or the other to the mains.

It is obvious that when the 4-pole machine is coupled to the mains, assuming that the periodicity is 50 per second, the synchronous speed will be 1,500 revolutions per minute, and when the 6-pole machine is coupled, the synchronous speed will be 1,000 revolutions per minute.

Therefore, to store energy in the flywheel, the throw-over switch is put on to the 4-pole machine, and to take energy from the flywheel, the

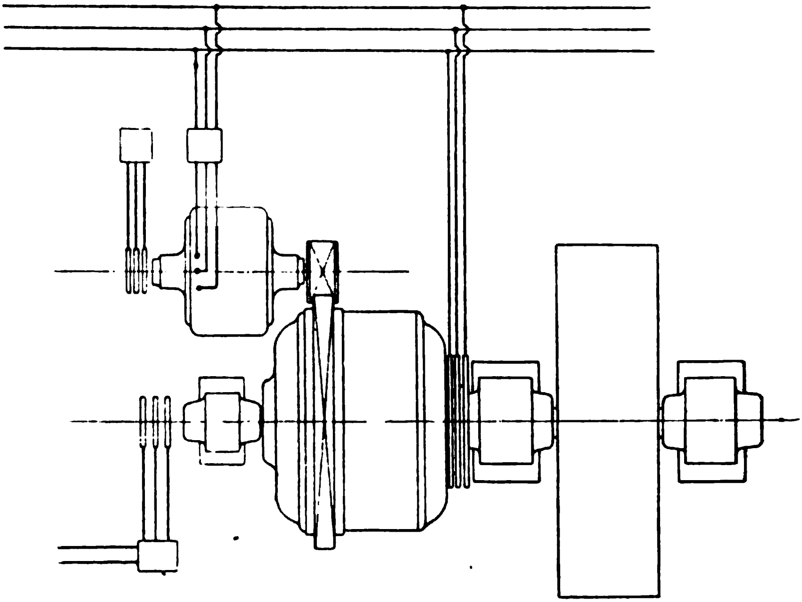

FIG. 5.

throw-over switch is put on to the 6-pole machine. The latter will, of course, then deliver energy back to the mains until the speed of the flywheel is reduced to 1,000 revolutions per minute.

The disadvantage of this system is that it is somewhat costly, and probably might give trouble with the switchgear, as heavy currents have to be made, and broken, on the throw-over switch.

The power factor, of course, is better than that of the cascade system, but it still has the disadvantage that the magnetising current for the flywheel system has to be supplied from the mains; therefore the only logical conclusion to come to was that it was necessary to use a synchronous motor coupled to the flywheel set, which can, if necessary, be over-excited so as to give unity power factor on the supply mains.

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A synchronous motor necessarily must run at a constant speed, and, therefore, no energy can be put into the flywheel, or taken out, unless either the periodicity is altered, or the stator is revolved. The latter method, therefore, offered a very simple means of getting over the difficulty, and resulted in a new patent being taken out for a synchronous flywheel storage system. As this is undoubtedly the best system of the three, I propose to describe it at somewhat greater length than I have devoted to the other systems.

The flywheel storage set consists, as before mentioned, of a synchronous motor with a revolving stator; the rotor of this machine is of rather peculiar design, being almost exactly similar to a wound rotor of an induction motor (see Fig. 5). This motor is started up exactly as an induction motor, that is, with a resistance in each leg of the rotor, this resistance being gradually cut out, as the flywheel attains its maximum speed. Suppose for a moment that we decided to use a 6-pole machine, and the periodicity is 50; this will mean that the flywheel will run at 1,000 revolutions per minute when the stator is stationary. As soon as the speed is near synchronism, continuous current, supplied from another source (such as the exciter on the main generator) is connected to one leg of the rotor windings, and the common junction thereof, the rotor being, of course, star wound. The motor at once pulls into synchronism, and no phasing indicators are required whatever.

The two unused legs of the rotor winding are then short-circuited and form amortisser windings, the advantage of this being that it gives the synchronous machine a large overload capacity without coming out of step.

The stator is carried on ball bearings in the nose of two pedestal bearings attached to the bedplate, and is geared to a small 3-phase or continuous-current motor, by spur, or skew gearing (see Fig. 6).

I prefer to have this small auxiliary motor reversible, so that it will run at a speed of, say, 1,200 revolutions in either direction. It will, therefore, be obvious that when the stator is revolving in the opposite direction to the rotor at, say, 200 revolutions, the synchronous speed of the flywheel will be 800 revolutions per minute, and if the stator is revolving with the flywheel at 200 revolutions the synchronous speed will be 1,200 revolutions per minute.

Of course it is quite easy to arrange to run the stator at a higher speed than this in both directions, if required, but, generally speaking, it is not desirable to vary the speed of the flywheel to the extent of more than about 1 to 1·5. This auxiliary motor is, of course, very often stopped, and therefore it can be assumed that the capacity of it is only about one-fifth of that of the main flywheel motor, allowing for gearing losses. The main winding motor, of course, is 3-phase, and takes its current at full pressure from the mains, the starting being effected through resistance in the rotor, preferably of the liquid type.

After the flywheel has been speeded up to its maximum (that is, by revolving the stator at 200 revolutions per minute in the same direction as the flywheel) the main motor is started up, the speed of the flywheel

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being reduced by gradually stopping, and afterwards reversing the motor controlling the speed of the stator. During this period the flywheel will be giving back energy to the supply mains.

Better control of this system can be obtained by using a small con-

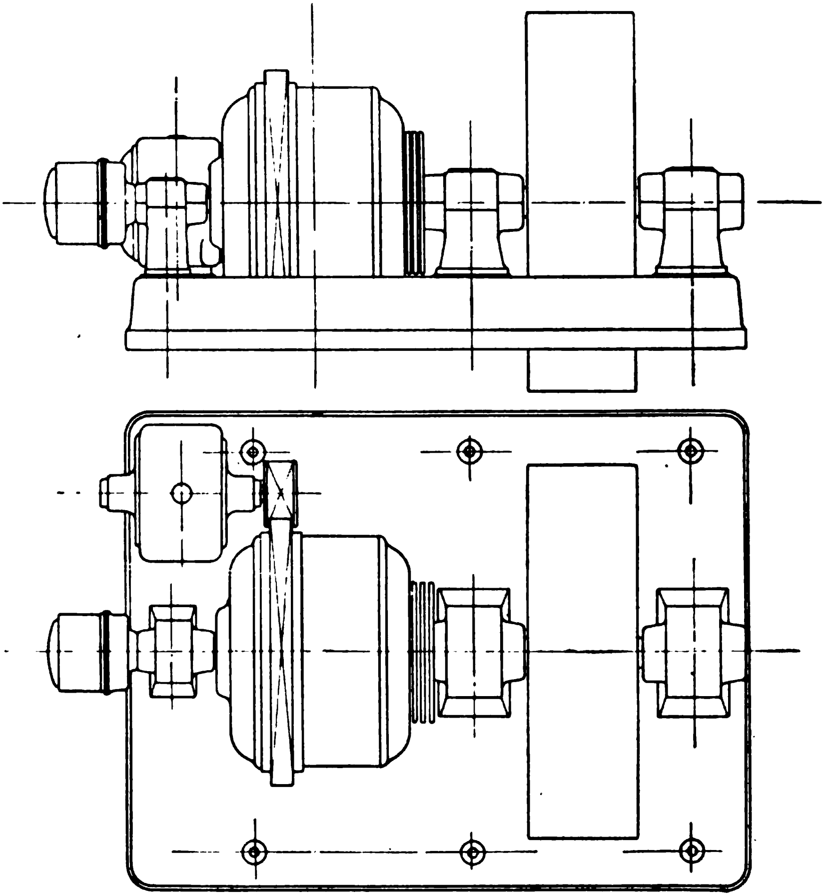

FIG. 6.

tinuous-current motor revolving the stator, this machine being supplied with current from a small continuous-current generator direct connected to the flywheel storage system, and the two machines controlled by the Ward-Leonard system, while the excitation is effected from the exciter on the main generator.

In order to control the main winding motor, it is necessary first to have a lever arranged to open a valve, and admit water to the resistance

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tank connected to its rotor; at the same time, this lever must control a Ward-Leonard shunt rheostat which controls the speed of the stator case.

The readings (vector diagram, Fig. 7) taken on a flywheel storage set arranged as above will give an idea of its superiority over the cascade system, particularly as regards power factor.

In pointing out the advantage of this system as compared with the one using continuous current for the main winding motor, attention must be called to the fact that it is possible to use a flywheel running at a high speed. With this construction we can use a comparatively light flywheel, as it is possible to obtain a flywheel built up of armour plate which can run at a peripheral speed of 28,000 ft. a minute, and with a large factor of safety. Such wheels are made and can be guaranteed by manufacturers in this country.

It is, of course, necessary to use a slow speed on the Ilgner system, owing to the fact that a continuous-current dynamo is attached to one end, and this dynamo has to work under very difficult conditions. It must, of course, be capable of delivering its full

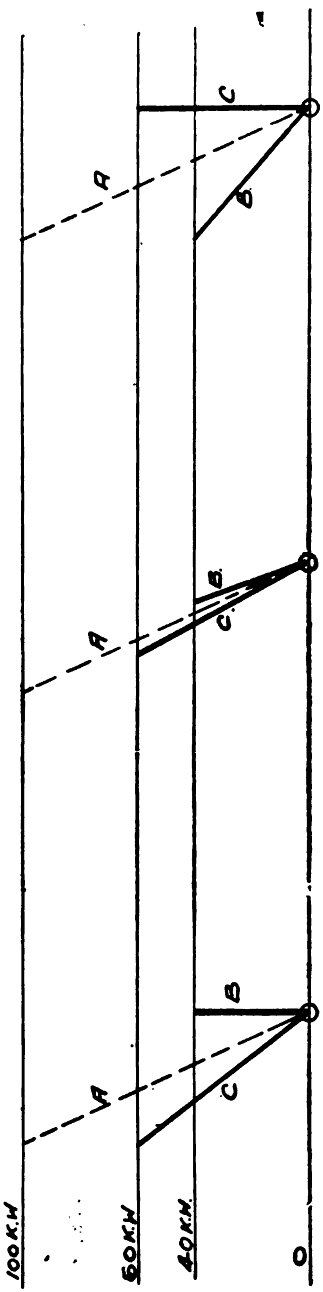

FIG. 7.—Diagrams showing different Currents on Flywheel Set and Main Generators for the same Load at varying Power Factors.

Winding Motor A — — — 100 k.w. cos θ = 0·9
Flywheel Set B ═══ 40 " "
Main Generators C ━━ 60 " "

current with practically no volts, and although it is fitted with interpoles and compensating windings, it is not possible with present practice to run these flywheel sets at a very high initial speed.

In flywheel systems where a large amount of energy has to be stored up in the flywheel, it therefore becomes almost impossible to build a flywheel which can be transported on the railway for these slow speeds owing to the large diameter. These flywheels necessarily must be made of the plate pattern, and in one piece, and unless the colliery is situated at, or near, a seaport town, it is practically impossible to transport the flywheel to the site on which it is to be used. The 3-phase flywheel storage system, therefore, does away with this difficulty, as the flywheels are of comparatively small diameter. They are also lighter on account of the considerable amount of energy which can be stored up in the rotor of the synchronous machine.

It will be observed that in the system which we have patented the full power required for the motor does not pass through the flywheel set, which simply acts as a buffer dealing only with such proportion of the current above that previously determined to be taken from the generator or source of supply, the normal energy going direct to the main motor without being transformed in any way. This, of course, means low capital cost, as the flywheel system is of relatively small capacity and high efficiency, as the major part of the current is supplied direct to the winding motor.

Attention must also be called to the fact that in many collieries they require to run the main winding engine intermittently during the night for lowering timber, etc., and for lifting water. With the above system, the flywheel set can be shut down entirely, and the main motor simply run on a slower acceleration in order to keep down the peaks. There is also, as a rule, plenty of reserve power on the main generators during the night-time, as the electric hauling engines down the pit, in addition to many other motors, will not be at work. Under these conditions, therefore, it is better to shut down the flywheel set at night altogether. Attention has been called to the fact that by varying the exciting current of the flywheel set, the power factor on the mains can be raised to unity, if necessary, but, of course, it is not desirable to do this to a too great extent owing to the fact that magnetising current does not represent energy, and, therefore, the flywheel set cannot help the main motor much if it is delivering wattless currents for magnetising to a too great extent.

A group of two or three main winding engines within reasonable distance for a high-tension transmission can be advantageously driven from one central station with one common flywheel storage set.

The flywheel storage set in this case is controlled by a solenoid or small induction motor actuated by the main current coming from the generator and starting, stopping, or reversing the small motor driving the stator on the flywheel set according to the current demanded by the various winding motors.

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This method can also be applied to equalise the load on any system (a group of rolling mills, for instance).

In comparing the cost of running of electric as against steam winders, the comparison ought to be made on a proper basis. It is generally admitted that electric power is desirable for practically all other operations in the pit, and, therefore, the cost of this generating

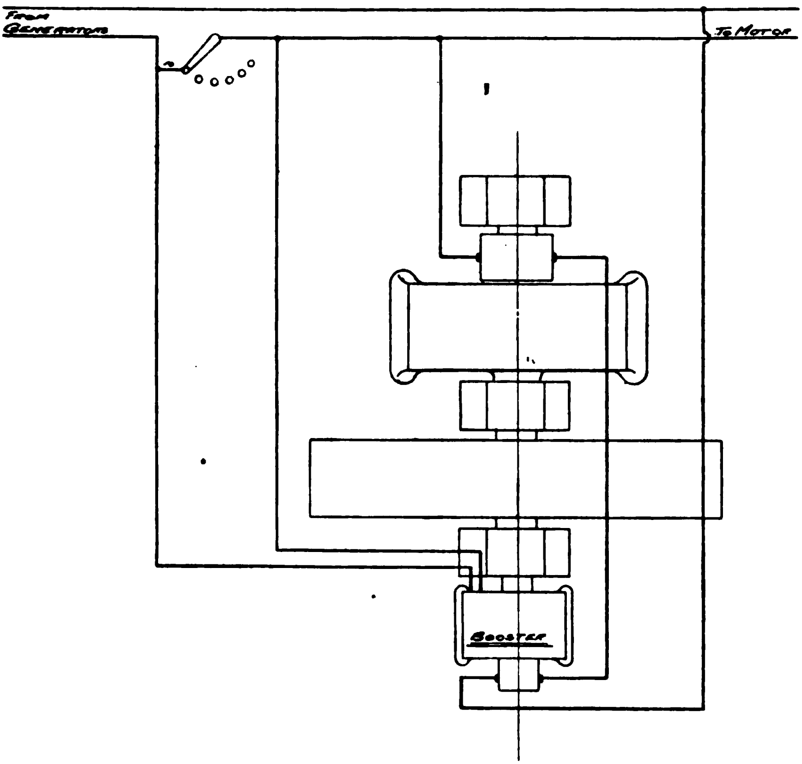

FIG. 8.

plant for the auxiliaries ought to be taken into account in comparing the two systems.

Assuming for a moment that the auxiliaries require 1,000 k.w. With steam winding, this would mean three generating sets, each of 500 k.w., allowing one set as a spare. With electric main winding taking an average load of, say, 800 k.w. from the mains (making a total load of 1,800 k.w.), the total capacity of the generating plant required would be 2,700 k.w., assuming that we have a standby set of 900 k.w., *i.e.*, three sets of 900 k.w. each.

The first cost of the larger plant will be considerably less per kilowatt than the smaller, and the coal consumption per kilowatt-hour will be less.

The first cost of the boiler installation will be considerably less with electric winding, and there will be no difficulty in using water-tube boilers, which are perhaps more suitable for burning low-grade fuels and for large powers.

Water-tube boilers can only be used with success with steam winding if there is a considerable amount of steam taken for driving other engines, as the water-tube type is not suitable for the heavy drafts of steam required in steam winding.

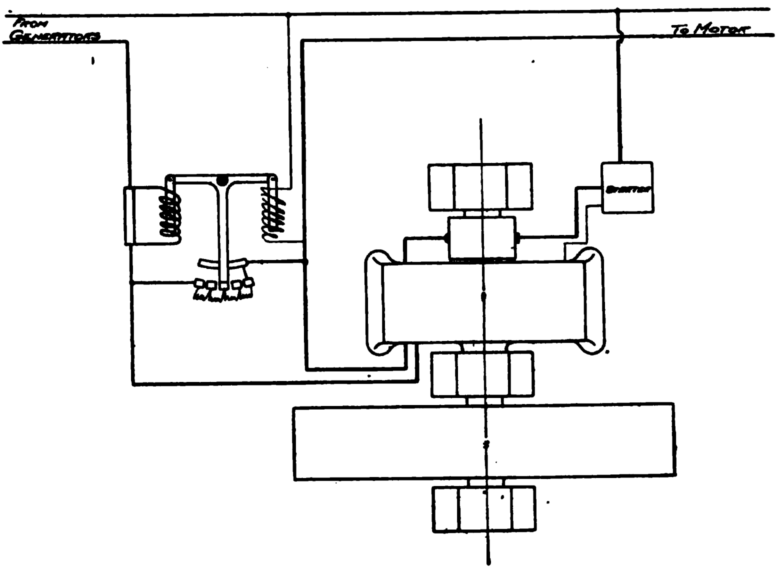

FIG. 9.

It may interest some of the members to know that some of the largest collieries in the South Wales district have as many as 70 Lancashire boilers.

Continuous-current Systems.—The two systems which I propose briefly to describe in this paper we will call the Booster Flywheel Storage System (see Fig. 8), and the Compound Flywheel Storage System (see Fig. 9). In the former a plain shunt-wound generator excited across the mains is attached to a heavy flywheel, and its armature is coupled up in series with an automatic reversible booster, constructed according to the Turnbull and McLeod patents. This booster has been very fully described in papers read by Mr. Turnbull and Mr. Kelsall before the Institution. I, therefore, do not propose to describe it in detail. The main fly-

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wheel dynamo simply takes the place of the battery, and if the demand on the line is heavy, the booster will give a voltage in such a direction as to pull current out of the flywheel dynamo, and when the demand on the line is small the booster will give a voltage in such a direction as to charge or speed up the flywheel set. The speed of this flywheel set will correspond directly to the voltage across the armature terminals, as the dynamo is excited at constant pressure across the mains.

There are not many cases where this system will be applicable, but it might be of service to some tramways, in addition to a main winding plant, when the peaks are of short duration.

The flywheel system is, of course, of no value if the peaks are carried on for a period exceeding three minutes, as the first cost of the flywheel to store a sufficient amount of energy for a longer period than this is so enormous.

The compound flywheel storage system (Fig. 9) consists simply of one machine which acts alternatively as generator and motor, and is coupled to a heavy flywheel, and worked in conjunction with automatic switchgear to vary its field strength.

In the typical case, briefly stated, the auxiliary machine is compounded to give constant external volts at all loads, whether motoring or generating. Its armature is connected across the mains between the generating plant and the fluctuating load, and its fields are equipped with a special series coil, carrying the generator's load, or some proportion of it. As long as the flywheel auxiliary's speed remains the same, the generator's load cannot alter, for the smallest tendency of the generator's current to increase, strengthens the auxiliary machine's field, causing a generating response, and similarly the smallest tendency of the generator's current to diminish causes the auxiliary set to motor.

As the auxiliary sets speed up, due to motoring, the automatic switchgear diverts an increasing fraction of the generator's current from flowing through the special coil of the auxiliary set, so that the field of the auxiliary set is gradually weakened without diminution of the load on the generating plant.

Similarly as the auxiliary set slows down, due to generating, the automatic switchgear gradually reduces the fraction of the generator's current diverted from flowing through the auxiliary's field, so that the auxiliary's field is strengthening, without increase in the load upon the generator.

However much the load varies, the demand upon the generating plant is only the average demand, all the excess demand of the peaks being supplied by the auxiliary set from energy stored during the valleys of demand.

In conclusion I can only say that I am sorry not to be able to give any actual results of working of the above systems, but before very long I shall have some actual results which will probably be published in the electrical papers. I hope that the systems which

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I have described will be criticised, and that there will be a good discussion.

Discussion.

Mr. Corlett. Mr. G. S. Corlett: There are one or two points I should like to suggest to Mr. Wood for his consideration, and several points on which I should like some additional information. Mr. Wood has tabulated five essentials for winding plants. I take it that the paper is mainly intended to apply to colliery winding plant, and that the allusions to rolling mills are more or less incidental. It seems to me that the first consideration, and one that ought to be printed in very large type, is reliability, because it does not matter at a colliery how beautifully efficient a thing is when it is working, if it does not work regularly, so that it is good policy at times to make certain sacrifices of efficiency if by so doing one secures greater reliability. Mr. Wood has given one typical curve of a winder, which is no doubt correct in one particular instance, but the actual working conditions of collieries vary so enormously that it is very difficult indeed to form any general set of conclusions without taking the mean of an enormous number of conditions in different places. For instance, in some collieries we get three complete winds per minute, and in others we have to struggle to get one. Mr. Wood has described a system where he changed over from a 6-pole to a 4-pole motor. I would like to ask what amount of current that motor took while accelerating. With regard to Mr. Wood's remark as to the flywheels for the Ilgner system being so large as to be non-transportable, I think that is more or less imaginary. I have seen a number of the flywheels on converter sets in the Westphalian district, quite a long distance from the seashore, and they did not appear to me to be of such dimensions as to prevent them going on railways; they were about 6 ft. in diameter. Mr. Wood mentions another point which I think more or less imaginary, viz., that it is necessary to run an Ilgner set at a slow number of revolutions, because we have continuous-current dynamo machinery. I think there are dynamo makers who are building turbine sets who would supply continuous-current dynamos to run as quickly as might be required. Taking Mr. Wood's paper as a whole, the only comparison one can make is the comparison between the arrangement shown in Fig. 3, which Mr. Wood seems to think is the most suitable, and what is known as the Ilgner system. I have had some little experience with the Ilgner system, but nobody has yet had any experience with Mr. Wood's arrangement in practice, and while the latter is extremely pretty, and extremely ingenious, and has certain advantages over the Ilgner, in that if the whole arrangement should break down from any cause whatever, one can still go on working, it seems to me that the difficulty of control in Mr. Wood's arrangement would be enormously greater than in the Ilgner. As no doubt we are all aware, the whole control of the Ilgner winding plant is effected in the shunt of the machine. The main current is never broken, and

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consequently the operating mechanism is very small, and therefore inexpensive to keep in order. Further, the speed of an Ilgner winder can be varied within enormous limits, and is practically independent of the load, so that in practice we can run just as steadily at, say, one-tenth of the normal speed as at full speed, and whether there is full torque on or practically no load whatever. In the case of a large 3-phase winding motor such as Mr. Wood refers to, taking, say, a maximum horse-power of 1,800, I rather think that the switchgear to stop and start the arrangement at least once per minute, and also to regulate the speed within the necessary limits, would be a somewhat elaborate piece of mechanism. Another point is that in case of failure of supply, with an Ilgner system there is sufficient energy stored up in the flywheel always to bring the cage up and complete the journey, and possibly considerably more than that, but certainly not less, and that obviates any danger of the men being hung up in the shaft. I am a little uncertain whether Mr. Wood thinks it would be possible to obtain the same result with this arrangement. Mr. Corlett.

Mr. J. S. PECK: I quite agree with Mr. Wood in that there are numerous advantages of the so-called buffer system over the Ilgner system. I also agree with his statements concerning the weights of the flywheels and the difficulty of transporting in Great Britain the heavy flywheels required by the Ilgner sets. There is one other feature affecting the design of the flywheels not mentioned by Mr. Wood. This is that with the Ilgner system only a limited amount of slip in the induction motor can be allowed on account of the rheostatic losses, so that it is not customary to drop the speed of the flywheel more than 12 per cent. or 15 per cent., whereas with Mr. Wood's system or with the "converter" system, the speed of the flywheel can be varied to practically any extent desired. The "cascade" system, described on page 417, was first shown to me by Mr. Rudolf Braun nearly two years ago. A patent was taken out on the system, but nothing further was done, as the difficulties pointed out in the paper were foreseen, that is, the low power factor which must result, but in addition to the lower power factor there would be heavy rheostatic losses in the regulating devices necessary for controlling the amount of power supplied to or taken from the line. The same arguments apply to a certain extent to the second scheme illustrated in Fig. 4, that is, the power factor would be low, though better than in the cascade system, and the rheostatic losses in the controlling devices would be large. The third system illustrated in Figs. 5 and 6 is the most important part of the paper. It strikes one immediately that there might be serious mechanical difficulties in a system of this kind. The method of supporting the heavy stator upon ball bearings mounted on projections from the pedestal bearings; the great difficulty of adjusting the air-gap; the thrust on the bearing due to the gearing; the noise from the gearing, are points which will have all to be carefully considered, but all the difficulties cannot be predicted until a complete mechanical layout of the system has been made, and the Mr. Peck.

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Mr. Peck. probabilities are that these difficulties will increase rapidly as the size of the equaliser is increased. The electrical difficulties must also be considered. The induction motor which drives the stator will prove to be a very inefficient arrangement. Suppose that the flywheel has been brought up to its maximum speed so that the stator is rotating in the same direction as the rotor. In order to get the energy out of the flywheel, its speed must be reduced. This means reducing the speed of the stator, which can be done by applying a mechanical brake, or the induction motor can be made to act as a brake. In order to make the motor act as a brake, it must be reversed. At the instant of reversal, it would be operating with approximately 200 per cent. slip, and the rotor would generate a voltage twice that which it would if held stationary, so that for the instant there would be a rheostatic loss in the rotor circuit equal to twice the full-load rating of the motor. With the arrangement shown, the capacity of the small motor is about 20 per cent. of that of the main motor, so that at the instant of reversal there would be a loss in the resistance in the rotor circuit equal to 40 per cent. of the output of the flywheel generator. Half of this energy is supplied from the flywheel, and half from the 3-phase circuit. When the stator speed is zero, the loss in the rotor circuit of the small motor is 20 per cent. of the output of the flywheel generator. That loss drops to approximately zero when the stator has reached full speed in the opposite direction. In accelerating there is a similar loss, the average over the whole period being 20 per cent. of the output of the generator. With a loss of 20 per cent. during the charging period, and a similar loss during the discharge period, the efficiency will be somewhat higher than 60 per cent., assuming no loss in any other part of the system. With these additional losses, the efficiency would probably be little better than 50 per cent., which means that this system cannot compete with the Ilgner system. For it must be remembered that in those buffer systems, where an A.C. motor is used for winding, there is a heavy rheostatic loss in starting the motor, whereas with the Ilgner system, using a D.C. winding motor, voltage control is obtained and rheostatic losses are eliminated. Mr. Wood proposes in the next arrangement to use a direct-current motor instead of an alternating-current motor. That, however, requires a direct-current generator for driving the D.C. motor, which can be driven from the flywheel shaft. An exciter will, however, be required in the great majority of cases for exciting the fields of the flywheel generator and the two auxiliary D.C. machines. That exciter must be driven at constant speed, and it will therefore be necessary to instal a separate motor for driving it. With the system thus arranged, suppose that the flywheel is revolving at maximum speed, and it is desired to retard the stator. The stator drives the small motor as a generator, which drives the second D.C. machine as a motor, which in turn tends to speed up the flywheel, so that the action of one auxiliary machine opposes that of the other, but as the torque upon the stator is greater than that upon the flywheel shaft, the flywheel will slow down. With this system, the auxiliary

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apparatus required consists of two direct-current machines, each having a capacity 20 per cent. of that of the flywheel machine, also an exciter and motor for driving it. The losses in all those machines will be rather large, but the efficiency should be much better than when the stator is driven by an induction motor. It appears that the problem of controlling that system will be difficult and complicated. Mr. Peck

Mr. J. FRITH: I agree with the other speakers that the diagrams look exceedingly interesting and as if they might work. One is not sufficiently familiar with such apparatus when it is put under these very unusual conditions. One does not exactly know, for instance, what will happen to a synchronous motor when the stator revolves one way and the rotor the other, one can only say that in general it looks all right, but it has to be tried. Then turning to another point, nobody has said anything about the plan of substituting a flywheel D.C. generator for a battery, with an automatic booster. I think the idea of using a shunt-wound generator coupled to its flywheel as a battery, and letting it float on the line as a battery, controlled by a reversible booster charging and discharging it, is a very good one, and seems to be much more practical than some of the other arrangements mentioned. Mr. Frith.

Mr. ECKMANN: The question of the size, efficiency, and other troubles of the different machines belonging to the new flywheel storage system having been already discussed, I will confine myself to some remarks on the controlling gear required for Mr. Wood's system. I will pass over the controllers for the cascade system and the system with flywheel and two independent motors, and consider only the rotary system with the Ward-Leonard auxiliaries, which seem to represent the latest developments of the new system. It occurs to me that the controlling of both the Leonard generator and the winding motor by the same lever, as pointed out in the paper, cannot lead to any good equalising. With that arrangement the voltage of the Leonard generator and the speed of the revolving stator are dependent on every change of the position of the control lever. Any sudden change, which, as is well known, is often made in connection with 3-phase winders, will result in a sudden change of speed of the revolving stator, and as the flywheel cannot follow those sudden changes the rotary will come out of step, or some fuses will blow. Even if these difficulties can be overcome somehow, perhaps by introducing an automatic control for the auxiliary machines, it appears to me that the control gear would have to be of such a complicated nature as to make the new flywheel storage system practically impossible. Mr. Eckmann.

Mr. H. A. EARLE: I should like to mention a few points irrespective of the actual design of the apparatus. Mr. Wood has stated that electrical winding is not commercially practicable unless coal at the pit head exceeds in value 2s. 6d. to 3s. per ton. The Yorkshire Electric Power Company is, however, buying coal from the collieries, and supplying electrical power to them for winding and pumping and other purposes, Mr. Earle.

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Mr. Earle. and therefore I think such systems are practicable notwithstanding a higher cost of coal. I have to-day been in Chesterfield, where I am interested in some large works, and where the conditions are very similar to those of winding, namely, rolling mills, spinning mills, hydraulic, draw benches, etc., and there I have been examining into the question of whether electrical power or steam power should be used. One mill, for instance, at Chesterfield takes 800 H.P., runs for 1½ minutes, and then shuts down for 5 minutes, when the process is repeated, and other plants take about 200 H.P. and 180 H.P. respectively, with about the same time interval, and I would like to know to what extent those systems in any given case would reduce the maximum demand. The author has also said that with flywheel storage the boiler power can be considerably reduced in cost. I should like to know by how much. I desire to ask the author whether for such work he would recommend the D.C. or a 3-phase system. It has been pointed out that with some systems if the flywheel breaks down the rest of the plant cannot be used, but it appears that if the same system were maintained throughout, one would not be independent of the flywheel plant. With regard to electrical winding, I think colliery people quite believe in its future, but the confidence in its reliability alone delays its more general introduction.

Mr. Cooper. Mr. A. G. COOPER: It seems to me that there is a great deal of money spent in all the apparatus that has been mentioned. Would it not be just as well spent, and with a great deal less complication, by putting it into the generating plant itself? It seems to me that the only advantage connected with the buffer system, or any system of that sort, is to try and do with a smaller generator and a smaller engine. Why should we not make the generator so much bigger, and the flywheel so much bigger, instead of putting the money into all that auxiliary apparatus? If we had a big flywheel on the generator we need not necessarily increase the size of the engine. With regard to the question of the boilers, I do not see why that system should have anything to do with the boilers. If we take, say, from the boilers 800 H.P. at one moment, and the curve comes down as shown on the diagram, the water taken over the whole time will be practically the same, and the whole thing will level itself out.

Mr. Field. Mr. M. B. FIELD (*communicated*): Mr. Peck raised the question of the action of the system described on page 421, where the stator and rotor of a synchronous motor are both mounted so as to be capable of rotation. To the rotor a heavy flywheel is attached, and over and above this, a direct-current machine, which we may call B, is geared to this portion; while another D.C. machine, which we will call A, is geared to the stator. A and B are electrically connected together so that the one may supply power to the other, the excitation of one or both of these machines being supplied from an outside source. Now, at first sight it certainly does seem strange that a self-contained system of this description—that is, a stator mounted in bearings pulling magnetically upon a rotor mounted in bearings, the rotor being geared to a

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dynamo which generates current and drives a motor geared to the stator—can be made to change its speed and absorb or give out energy by merely varying the excitation of the machines A and B, but such is undoubtedly the case. Mr Field.

If T be the torque exerted on the rotor by the rotating magnetic field generated by the stator windings, and if N be the angular velocity of the rotor relatively to the stator, the power transmitted to the rotor from the line supplying the stator will be T N.

Now, obviously, by means of the motor and generator, A and B, it is possible to exert an independent torque between stator and rotor; in other words, to vary the amount of torque with which the magnetic field, due to the stator windings, pulls upon the rotor; but, since the power delivered by the line is $T \times N$, obviously varying the current flowing between A and B, must vary the input or output from the line.

Suppose, for the sake of argument, there are no losses in the system. Let the synchronous angular velocity between rotor and stator be N, and let at some particular instant the motor A be driving the stator in the same direction with an angular velocity M. For the present purpose it does not much matter where the current comes from which drives the motor A. Let, furthermore, the flywheel portion be driving generator B, which is loaded up by means of a water resistance. The power delivered to the flywheel system is obviously the torque T multiplied by its total angular velocity, or $T(M + N)$, this power being utilised partly in driving B, and partly in accelerating the flywheel if the speed be changing.

Now, as the angular velocity of the rotor relatively to the stator is N, the power delivered by the line is T N; also, as the stator is driving the rotor with a torque T, and is itself mounted in bearings, it must obviously be driven forward with a torque T by motor A; consequently, the power is delivered by A to the system is T M. Thus T M is delivered by A; T N is delivered by the 3-phase line; the power delivered to the flywheel system is $T(M + N)$, and part of this at least goes to drive generator B. We can now assume that the water load on B is exactly equal to the input of A. Now, the input of A is T M; consequently B will react upon the flywheel system with a retarding torque equal to $\frac{TN}{M+N}$. As B now is giving out as much power as A is absorbing, they might just as well be coupled together, the one driving the other, and we then have the condition of things that the torque exerted upon the rotor is T, while the backward torque due to the rotor driving B is only $\frac{TM}{M+N}$. There is, therefore, a balance of torque exerted upon the rotor tending to accelerate it.

The whole matter put in a nutshell is explained thus: Although the rotor gives out to B the same amount of power that the stator absorbs from A, owing to the much higher speed of the rotor relatively to that of the stator, the retarding torque exerted by B must be much smaller than the accelerating torque exerted by A; consequently, when power

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Mr. Field. is given out by the flywheel to B and absorbed mechanically by the stator from A, the torque between the stator and the rotor is varied, and current flows in from the 3-phase line, the whole system accelerating, and the reverse occurs when it is desired to take energy out of the system. It certainly appears to me that this is the only device proposed by Mr. Wood which can, in the very nature of things, be at all economical. It is difficult to see how the proposal to employ an induction motor in place of A can be anything but extremely wasteful of power.

Mr. Wood has not given us much information about his mechanical arrangements, and the proposal to rotate the stator on ball bearings from the noses of the pedestals carrying the rotor is not a very appetising one. I think a more hopeful construction would be to have both rotor and stator overhung and mounted on stiff shafts carried in very substantial bearings.

Mr. Wood. Mr. WOOD (*in reply*): I do not think it advisable to recommend systems which are not suitable for any particular object, but there are undoubtedly many cases where flywheel storage is suitable for tramways. The peaks on tramways very seldom extend over half-minute, but the flywheel system is usually not so good as a battery and booster, as it can, of course, not supply energy during the night-time for marshalling and testing the cars in the shed, etc. I purposely did not mention the question of switchgear, as I am making experiments which may be the subject of further patents.

In reply to Mr. Corlett, as regards reliability, the systems described are ideal owing to the fact that a breakdown of the flywheel storage system would not stop the winding. I am, of course, aware that every case of winding must be considered on its own merits, but to put the matter briefly, the buffer system is the most suitable where the winds are long. As regards Fig. 4, resistance is introduced in the rotor when changing over from 4-pole to 6-pole, or *vice versâ*, so as to prevent any great rush of current. These resistances are shown in Fig. 4 in the form of a box. Regarding the diameter of flywheels, I know of a works in Hungary where they have two flywheels, each 4 metres in diameter, and weighing about 26 tons each. Mr. Corlett will find that my contention as to slow-speed flywheels sets is correct. It is true that continuous-current turbine sets have been made to work perfectly satisfactorily, but the conditions of flywheel generators on the Ilgner system are quite different. At starting the generator has to develop about double load current with practically no voltage, as it is controlled by the Ward-Leonard system. As regards the difficulty of controlling the synchronous system, Fig. 5, this is not so difficult as one might think. In the system recommended, that is, with a D.C. motor for turning the stator case, the control of the D.C. motor would be automatic according to the load, the control being effected through a 3-phase series solenoid or small 3-phase series motor, such as are used for electric cranes for controlling the brake. Therefore the only switches to be controlled by the operator after the buffer set has once

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been started up are the reversing switch for the main winding motor and the liquid starter for the same. Of course the synchronous buffer system has the same advantage as the Ilgner system, inasmuch as the wind can always be completed in case of failure of the main supply. Mr. Wood.

In reply to Mr. Peck, the "slip" in the Ilgner system can be made as much as 30 per cent. if desired by introducing a greater amount of resistance in the rotor. As regards the cascade system, Fig. 2, he has been good enough to send me a copy of Mr. Braun's patent, and I find that this is practically the same as my own. Mr. Braun's patent was, however, taken out at a later period than mine. As regards the mechanical difficulties of the synchronous system, these simply do not exist. The ball bearings on the stator frame are very satisfactory, and will run for weeks without giving them a further supply of grease. If worn, it is, of course, a very simple matter to adjust the balls by the cones. I quite agree with Mr. Peck regarding the inadvisability of using a 3-phase motor for revolving the stator case. I only recommend this for very small equipments, and I prefer the arrangement of using a continuous-current motor as described. The efficiency with this system is very high, as there are no rheostatic losses on the flywheel set whatever.

In reply to Mr. Frith, I thought I made it plain in the paper that I have had an experimental synchronous storage set built, and that it has been tested thoroughly under every conceivable condition, and it has withstood the test satisfactorily.

In reply to Mr. Eckmann, I agree that the best system for equalising the main current is to use an automatic control by a 3-phase series motor. The control is not at all difficult.

In reply to Mr. Earle, the reason why I said that electric winding is not practicable unless the value of the coal used exceeded 2s. 6d. to 3s. per ton, is that the interest and depreciation on the extra first cost over steam winding outbalance the saving in coal. In the case of supply from a power company the conditions will be, of course, quite different, as the first cost will be much less, and it becomes simply a question as to what the current can be bought at as to whether it will pay or not. As regards the mill at Chesterfield, this appears to be a case where flywheel storage would come in well. It is impossible to give any figure regarding the saving in first cost of the boilers. Each case is different and requires considering on its own merits. Generally speaking, I would advise the use of a 3-phase system, as it is more suitable in every respect for ordinary steel works. I confess I do not understand the last sentence but one. Presumably Mr. Earle refers to the Ilgner system with continuous-current main supply instead of 3-phase. If it is desired to use the winding motor in case the flywheel set breaks down, an alternative starting arrangement would have to be provided, consisting of a main resistance for starting the winding motor, in place of the Ward-Leonard control.

Mr. Cooper evidently forgets that a flywheel cannot discharge itself unless the speed is varied. The idea of a steam plant with each gene-

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Mr. Wood. rator fitted with a heavy flywheel, and with engines governing to, say, 20 per cent. between maximum load and no load, and a possibility of running away altogether on the latter load, would be too awful to contemplate ; also the speed of all the other motors on the system would vary with the engine speed, and probably some of them would come out of step. With steam winding, owing to the uneconomical conditions of running, the boilers are necessarily larger, and also on account of the large drafts of steam required during the actual wind. Possibly with thermal storage these conditions could be somewhat improved, but the first cost is very great in comparison with the saving.

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MANCHESTER LOCAL SECTION.

THE EXPERIMENTAL DETERMINATION OF THE LOSSES IN MOTORS.

By CHARLES F. SMITH, Associate Member.

(*Paper read April* 9, 1907.)

PART I.

DIRECT-CURRENT MOTORS.

Electrical Separation of Losses.—In 1887 Mr. Swinburne published in the *Electrical Review* his method of determining the losses in dynamos or motors.

He distinguished between the copper losses which may be directly calculated, and the stray power consisting of losses due to eddy currents, friction, and magnetic hysteresis. The stray power is determined by running the machine light as a motor, the field magnets being excited to give the same armature induction as at full load, and the applied voltage being adjusted to give the normal speed. The power required to run the armature under these conditions is taken to be also the stray power at full load.

It is remarkable to notice how little this method of determining the losses in a motor has been improved upon in the twenty years since it was published. The publishers of more recent methods have only succeeded in carrying the separation of the losses somewhat further (always under no-load conditions). The assumption made in the Swinburne test, that the friction losses may be taken to be constant for all loads, has been proved by G. Dettmar* and other writers to be true, for well-designed bearings, even when subjected to the stresses of a belt drive.

A method for the more complete separation of the iron and friction losses was proposed by Kapp and Housman † twelve years after the publication of Swinburne's test.

By this method the losses occurring in the machine when running as an unloaded motor, are divided into two parts, viz.: Losses which vary in direct proportion with the speed, and those which vary as the

* *Elektrotechnische Zeitschrift*, vol. 20, p. 651, 1899.
† *Electrician*, vol. 26, pp. 699 and 700, 1891.

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square of the speed. By running the machine at constant excitation and varying its speed by change of applied armature voltage, the driving power may be plotted in the form of a curve, giving the relation between the driving current and the induced back E.M.F. This curve is approximately a straight line. By continuing the curve to cut the vertical axis of co-ordinates, the height of the point of intersection gives the value of the current supplying the constant torque losses, *i.e.*, losses which are directly proportional to speed. Subtracting this current from the ordinates of the curve of total current, the portion of the current overcoming the losses which vary as a higher power of the speed are obtained. It is then assumed that the constant torque losses are due to hysteresis and friction, while the losses producing the slope in the current-volt curve, are due to eddy currents, which produce a torque proportional to the speed.

The assumptions upon which this separation depends, have since been found not to be accurate. The torque due to hysteresis is probably not a strictly constant quantity, while even brush friction has been found not to be a simple function of the speed, but to depend upon the current.*

Further, the increased loss due to windage at higher speeds is not taken into account.

A more accurate method, which is really a development of the one just described, enables the total frictional losses to be first determined, after which the iron losses are separated, as in the Kapp and Housman test. The friction losses for any speed are obtained from a curve showing the relation between driving watts and volts applied to the motor, plotted for a constant speed but variable excitation. By continuing this curve back to cut the vertical axis, corresponding to zero volts generated, *i.e.*, zero armature induction, we obtain the value of the watts overcoming friction alone. In order to obtain the point at which the curve should cut the axis with more certainty, the values of the squares of the volts, instead of the voltage, may be plotted horizontally. The lower points on the curve are thus brought nearer to the vertical axis.

By obtaining a number of such constant-speed curves for a range of different speeds, a curve of friction loss may be obtained, each constant-speed curve furnishing one point upon the friction curve. From the friction curve may now be obtained the current supplying the friction torque. By subtracting the current overcoming friction from the curve of total current obtained in the Kapp and Housman test, we determine the iron loss current alone. This remaining current may then be separated into eddy current and hysteresis components as in the former method. †

Incidentally it may be noticed that the *increase* with speed occurring in the friction current determined as above, must be due to windage, since the brush and bearing friction may be taken to require a constant

* *Electrical World and Engineer*, vol. 34, p. 417, 1899.

† This method was fully described with a worked example, by G. Dettmar, *Elektrotechnische Zeitschrift*, vol. 20, pp. 203 and 218, 1899, and is also given in several text-books dealing with the subject.

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current at all speeds within a wide range. The windage loss is thus given separately from the frictional loss.

The separation of the losses by this method gives very good and consistent results when carefully carried out. The method has the great advantage that no second machine is required ; it is, however, so laborious that its usefulness is much restricted.

Use of Auxiliary Motor.—The use of an auxiliary motor to drive the machine under test forms one of the simplest and most direct methods of measuring the no-load losses of a machine. In this method the no-load losses of the auxiliary motor are measured and subsequently subtracted from the power supplied to it when driving the machine to be tested, allowance only being made for change in C^2R loss. The effect of change of excitation, brush friction, etc., in the driven machine are thus measured as the amount of change in the power taken by the auxiliary motor. In carrying out the test, great care is required to ensure that the frictional losses in the auxiliary motor are exactly the same when tested light as when driving the second machine. A further point to be noted is the assumption that the internal losses of the driving motor are independent of load for the range of loads taken. From the point of view of accuracy, the method suffers also from the introduction of the losses occurring in the driving motor, which must in each case be measured with the losses to be determined. Additional elements of uncertainty are thus introduced without any corresponding increase in the accuracy of the method of reading. In simplicity and directness of application the method has great advantages.

Load Tests of Efficiency.—Methods directed primarily to the measurement of efficiency under load rather than the determination of the losses, will not be considered to come within the scope of this paper.

The Hopkinson tests will not, therefore, be referred to, as they are not primarily directed to the separate determination of losses, and, in fact, necessitate assumptions as to the distribution of losses between two machines which at best are only approximately true.

Retardation Methods.

A number of methods for separating the losses in a motor or generator all depending on the study of the retardation curves of an unloaded machine, were described by J. L. Routin,* J. Claude,† C. Liebenow,‡ and others of later date. These methods have now been widely adopted, and as they are described in many text-books dealing with the subject of testing electrical machinery, those principles involved which are not new will be here stated as briefly as possible.

General Principles.—The machine to be tested is run up to full speed, or to a speed slightly higher than full speed, and the armature is then disconnected from the source of power. The machine will be brought gradually to rest under the influence of the forces opposing

* *L'Eclairage Electrique*, vol. 9, pp. 169–172, 1896.
† *L'Electricien*, vol. 15, pp 42–44, 1898.
‡ *Elektrotechnische Zeitschrift*, vol. 20, p. 274, 1899.

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its rotation. These forces are due to the frictional and iron losses which occur in the rotating machine. The work done during any interval of time in overcoming these losses as the machine retards will be equal to the kinetic energy lost by the machine in this time interval. The kinetic energy lost per second is then the power overcoming the losses. Since the kinetic energy will depend only on the speed (for a given machine), it is not difficult to determine the variation in the losses, as the machine slows down, by taking observations of the speed at successive equal intervals of time. By plotting a curve of speeds on a time base, the rate of change of speed, and consequently the rate of change of kinetic energy, may be deduced when once the kinetic energy at any single speed has been determined.

In absolute units, the kinetic energy of a rotating body is—

$$\tfrac{1}{2} I (2 \pi n)^2$$

where I is the moment of inertia and n is the speed of the body in revs. per second.

Translated into practical units this becomes—

$$\text{Energy} = \frac{I n^2}{5{,}800} \text{ ft.-lbs.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where I is in lb. ft.² and n in revs. per minute.

Writing K′ for the constant quantity $\frac{I}{5800}$,

$$\text{Energy} = K' n^2.$$

Suppose the speeds observed at two successive readings near together to be n_1 and n_2, and let the mean of these be—

$$n = \frac{n_1 + n_2}{2}$$

then the mean power producing the change of speed—

$$= \text{energy lost} \div \text{time between observations}$$
$$= \frac{1}{t} K' (n_1^2 - n_2^2) = \frac{2 n K' (n_1 - n_2)}{t} \text{ ft.-lbs. per minute}$$

where t is the time in minutes between the readings.

Since 1 ft.-lb. per minute = 0·0226 watt

$$\text{No. of watts} = \frac{0{\cdot}0452\, n K' (n_1 - n_2)}{t} = K n \frac{n_1 - n_2}{t} \quad . \quad . \quad . \quad (2)$$

where $K = 0{\cdot}0452\, K'$.

The experimental retardation curve is plotted to a large scale with time measured horizontally and speeds vertically (see Fig. 1). At any point on it corresponding to a speed of n revs. per minute, the value of $n_1 - n_2$ is obtained by scaling the difference in height of the curve at

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speeds n_1 and n_2 at equal horizontal distances on either side of n. The value of t, the time interval corresponding to the difference $n_1 - n_2$, must be taken so small that the curve is practically straight within these limits. Usually the time interval between two successive readings would be suitable.

Arnold* has shown that instead of the expression $n \frac{n_1 - n_2}{t}$ the subnormal to the curve at the point corresponding to speed n may be taken.

Thus in Fig. 1—

$$\frac{n_1 - n_2}{t} = \tan \alpha = \frac{AB}{BP} = \frac{AB}{n}$$

$$\therefore \quad AB = n \frac{(n_1 - n_2)}{t}$$

and the watts spent in retardation at point $P = K \times AB$.

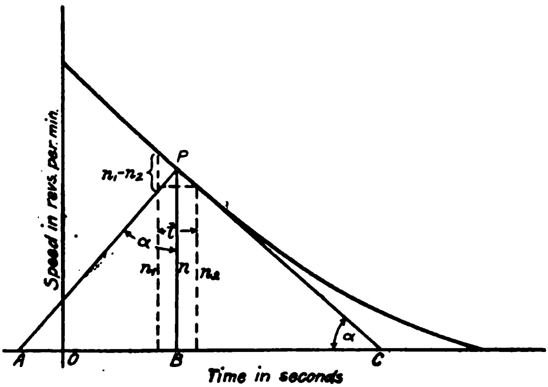

FIG. 1.—Retardation Curve.

Thus it is only necessary to measure the length of the subnormal AB and to multiply this length by the constant K.

In my own measurements I have found it best to measure off the length $t_1 - t_2$ as first described, employing spring-bow dividers for the purpose, rather than to measure the subnormal.

Determination of K.—The chief variations in the form of the experimental determination of losses by this method, as proposed by various experimenters, are to be found in the method adopted for the determination of K. As has been shown already the value of K is determined as soon as the moment of inertia of the rotating patrs of the machine has been found.

A summary of the chief methods available for finding the moment

* *Die Gleichstrommaschine*, vol. 1, p. 503.

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of inertia of an armature is given by Dr. A. Hay.* These methods are in outline—

1. By time of torsional vibration, the armature being suspended by a bifilar suspension of wire rope.
2. Measuring the time of retardation of the armature with and without the addition of a disc of known moment of inertia. The alteration in windage loss is likely to affect the accuracy of this method.
3. A comparison of the electrical power taken to maintain rotation at a certain speed with the rate of retardation when allowed to retard at the same speed from a higher speed.
4. Allowing the machine to retard from a high speed, both with and without an added retarding force obtained by allowing the armature to generate current in a resistance connected across its terminals.
5. Similar to the last, except that the added torque is produced mechanically by applying a brake, instead of electrically.

To these methods might be added the coupling of the machine to another whose constant has already been determined. From measurements of driving power required by the coupled machines, and from the retardation curve of the combination, the constant for the second one may be found.

Outline of Simple Test.—The employment of any of the last four methods enables the value of K to be determined directly, without an evaluation of the moment of inertia. Method 3 is the simplest to carry out in practice, and when it is adopted, the following procedure should be followed.

The machine must be run at the normal speed for a sufficient length of time for the bearings to get to the stationary condition as regards temperature. The watts taken at this speed are then noted, and the speed is raised. The machine is immediately afterwards allowed to retard, readings of speed at equal time intervals during the retardation being taken. For exact measurements, it is important to notice that there will be a normal running condition of the bearings corresponding to each speed, so that one no-load reading should be taken for each retardation curve, if several determinations of the constant are to be made. The value of K when once determined is, of course, constant for the machine and is independent of load, excitation, etc.

Taking of Readings for Retardation Curve.—After the value of K has once been determined, the only readings to be taken for the determination of the losses under any particular conditions, are those of speed and time. The percentage accuracy of the result will depend on the exactness with which these readings can be taken. The speed is generally best determined by using a high-resistance voltmeter connected to the terminals of the machine, since speed and voltage

* *Electrical Review*, vol. 47, pp. 287 and 327, 1900.

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at no load will be proportional to one another, and the residual magnetism will produce sufficient voltage to give satisfactory readings in the case of the unexcited machine.

If readings have to be taken in very rapid succession, owing to the shortness of the time of retardation, a strip of paper may be pasted on to the face of the voltmeter, and the positions of the pointer, as it moves across the scale, can then be marked with a pencil and afterwards read off at leisure.

The accurate timing of the readings requires a little practice if the intervals are short. I have found an ordinary metronome answer the purpose of timing the readings admirably.

Some interesting methods of simplifying the method of observation were given in a paper by Dr. Sumpner, *Journal, Institution of Electrical Engineers*, vol. xxi., p. 632.

Use of the Ondograph or a Recording Voltmeter.—An excellent method of taking the retardation curves where the time of retardation is short has been brought to my notice by my friend Mr. U. A. Oschwald, B.A., and through his kindness I am able to give particulars of some readings taken by him at the South Western Polytechnic in London.

According to this method the curves were traced automically by the Hospitalier Ondograph, which was used as a recording voltmeter. The synchronous motor of the Ondograph was driven by an alternator working at a constant speed, whereby the drum carrying the records was rotated at a uniform speed, making the horizontal scale of the record proportional to time.

By an ingenious arrangement, the galvanometer of the instrument, which produced the vertical motion of the recording needle, was connected to the terminals of the machine experimented upon in series with a voltmeter, which served as a series resistance for the galvanometer movement, and also made it possible (by merely closing a switch) to determine the value of the vertical scale of volts upon the chart.

The armature of the machine under test was connected to the galvanometer movement of the Ondograph in series with a voltmeter with 30- and 120-volt ranges. By means of a switch, the voltmeter could be directly connected to the terminals of the motor.

With the switch closed, the voltmeter indicated the machine voltage directly, the 120-volt scale being employed when the machine was excited, and the 30-volt scale when the machine was unexcited. By opening the switch, the Ondograph needle was actuated, the voltmeter then acting as a series resistance. The deflections of the Ondograph were checked and found to be proportional to the voltage applied; they were found to be 0·905 volt per mm. with the 120-volt scale of the voltmeter, and 0·278 volt per mm. when in series with the 30-volt scale. At the speed chosen, the horizontal scale of the chart was 21 of the degrees marked on the chart to 1 second.

The calculation of the constant K connecting the slope of the curve with the watts absorbed, was carried out in accordance with the method

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3 described on page 442, a series of very close values being obtained by alternately measuring the power required to drive the motor at a certain speed and determining the slope of the retardation curve at the same speed when slowing down from a higher speed. The tests were carried out on the 100-volt 100-amp. continuous-current motor of a motor-generator set. The motor had the unexcited rotating field of a 6-k.w. alternator coupled to it throughout the test.

In Fig. 2 I have re-plotted three curves from the Ondograph records, as the latter do not lend themselves to direct reproduction.

The curves show the rate of retardation with an excitation of 3·9, 1·9, and zero amps. respectively.

From these curves and the constant determined by previous

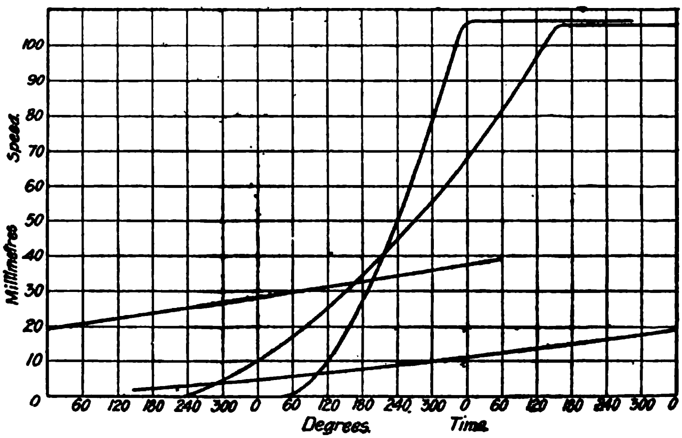

FIG. 2.—Ondograph Records.

Upper Curve	...	3·9 amps. excit.
Next Curve	...	1·9 " "
Bottom Curve	...	zero "

experiment, the iron and friction loss curves shown in Fig. 3 were plotted. The lowest curve represents the total friction and windage loss, and the ordinates between the upper curves and the friction curve represent the iron losses at the two values of the excitation taken.

The upper curves appear to be cut short, owing to the fact that the scale of the Ondograph was not adjusted to take the full voltage corresponding to maximum speed and maximum excitation.

The curves show the rapidity and accuracy with which a separation of the losses may be made by the use of some form of recording voltmeter. A simple form of recording voltmeter might be substituted for the Ondograph, but it need hardly be said that the recording instrument must be most carefully chosen, in order that friction of the pen or uncertainty in the speed mechanism may not render the results valueless.

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Several modifications might be adopted for increasing the accuracy of the readings. For instance, the voltmeter may be connected across the switch in the armature circuit so as to read the difference between the line volts and the motor volts as originally suggested by Dr. Sumpner. Also part of the scale of the voltmeter might be suppressed, so as to give a more open scale for reading the upper part of the retardation curve, which is the most important part.

Employment of a Flywheel to Increase the Inertia.—The time taken by a machine to come to rest will depend on the relation between the retarding forces due to friction, etc., and the inertia of the rotating parts.

Since the losses in small motors are relatively high, and the inertia of the armature is relatively low, the method can only be made applicable to such machines by making the readings automatic as just

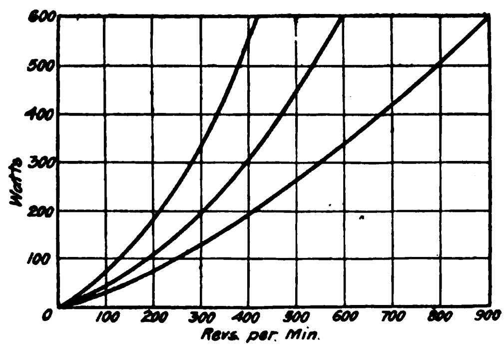

FIG. 3.—Calculated Loss Curves.

Top curve—excitation = 3·9 amps.
Second curve—excitation = 1·9 amps.
Bottom curve—friction only.

described, so that retardations of very short duration may be observed, or by lengthening the time of retardation by increasing the inertia of the rotating parts, for instance, by mounting a disc, or heavy pulley, on the shaft in place of the ordinary pulley or coupling. The addition of a moderate weight to the shaft will probably not increase the friction losses in the bearings, but will add to the loss in windage. A correction for this increased loss due to the added weight may easily be made by running the motor at the same speed, first with and then without the additional weight, the difference between the two driving powers would then represent increase in loss due to this cause.

Use of a Separate Flywheel.—A further advance in the direction of increasing the ratio of inertia to retarding forces leads to the suggestion that by sufficiently increasing the inertia of the rotating system, the retardation (or acceleration) curve might be employed for studying the losses in a motor when working under load. This would involve

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the use of a separately mounted flywheel, to which the motor may be coupled. The employment of a separate flywheel, to which the machine under test can be coupled, forms the basis of the tests described in the next sections of this paper.

Retardation and Acceleration Curves taken under Load.—Supposing the value of the constant K to be known with sufficient accuracy, observations of the speeds of the flywheel at successive equal intervals of time, when plotted on a curve, may be made to give a value for the power expended in its acceleration. The accuracy of this determination of the power depends, as before, only upon the accuracy of the readings of the speed and of the intervals of time between these readings. Given a sufficiently long interval of time between successive readings to enable these to be taken carefully, we have thus a means of measuring the power spent in accelerating or retarding the flywheel, requiring only the simplest of instruments, and free from the uncertainties attaching to most of the methods in ordinary use for measuring the output of a motor.

The method of determining the losses in a machine to be tested will then be carried out somewhat as follows :—

After a continuous run in which the machine has reached its normal working temperature, it is coupled to the flywheel. If of the shunt type, the motor field will be connected to a constant voltage, while the armature is connected to the supply mains through a finely adjustable rheostat, preferably of the liquid type in series with an ammeter. The machine is then made to run up to full speed, while the armature current is kept constant at its full-load value, by adjustment of the rheostat. During the acceleration, readings of the speed are taken at regular intervals given by a clock or metronome. If the total losses in the machine are required, the coupling between the motor and flywheel is now slipped out of gear, and readings of the flywheel speed are taken as it comes to rest.

From the plotted curve of acceleration, the power spent in producing the kinetic energy of the flywheel at full speed is obtained, and from the retardation curve of the flywheel alone, the power spent in overcoming its frictional losses. The sum of the two values of power thus obtained gives a measure of the total output of the motor at the speed considered, since this will be equal to the sum of the power spent in overcoming the friction of the flywheel and the power spent in accelerating it. By allowing the flywheel to retard from full speed with the motor on open circuit but excited, and still coupled to it, the ordinary no-load "stray power" losses of the motor may be obtained, after subtracting the flywheel windage and friction losses obtained before.

A retardation curve, corresponding to the acceleration curve obtained by making the motor drive the flywheel, may be obtained by causing the flywheel to drive the motor. For this purpose the motor is disconnected from the electrical supply after it has driven the flywheel up to full speed. It is then short-circuited on to the

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liquid rheostat, to which it thus supplies current, while the flywheel becomes the source of power in virtue of its kinetic energy:

By regulating the rheostat to maintain the constant full-load current, a similar curve to the acceleration curve is obtained from readings taken in the same manner.

The time of retardation under these conditions is less than the time of acceleration because the frictional and other losses now diminish, instead of increasing, the duration of the run. The retardation curve is, consequently, steeper than the acceleration curve.

When the motor under test is series wound, exactly the same method of procedure is adopted, except that a throw-over switch is necessary for reversing the connection between armature and field. The direction of the current in the field must, of course, be maintained the same during both acceleration and retardation.

Calculations from Acceleration and Retardation Cuives.—Perhaps the most interesting point in connection with the taking of a retardation curve as well as an acceleration curve is, that we are thereby enabled either to dispense altogether with the evaluation of the constant K for the flywheel, or to determine it with much greater accuracy than by the more usual no-load method. This may be done as follows: Let the acceleration and retardation curves be plotted in terms of induced voltage, instead of speed. As the excitation is assumed to be constant, the induced voltage is obtained by adding or subtracting the armature resistance drop (a quantity which may be assumed constant for the constant current) from the measured terminal voltage of the machine.

Let A be a point on the acceleration curve, and B a point on the retardation curve corresponding to the same induced voltage as A. Let v be the back volts at A and B.

Let—

$$\frac{dv}{dt} \text{ be the slope of the curve at A}$$

and—

$$\frac{dv'}{dt} \text{ be the slope of the curve at B.}$$

The watts spent in changing the kinetic energy of the system at—

$$A = K'' \frac{dv}{dt} v \text{ (see page 441)},$$

similarly watts at—

$$B = K'' \frac{dv'}{dt} v.$$

The current and induced voltage being the same in the armature for both cases, the watts which produce that part of the acceleration which is due to electrical and not mechanical causes will be the same. Let these be denoted by W. Since the speeds corresponding to A and

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B will be almost identical, we may assume the iron and friction losses to be equal for the two points. Let these losses be l—

Then total accelerating watts at A $= W - l$
retarding watts at B $= W + l$.

Hence—

$$K'' v \frac{dv}{dt} = W - l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and—

$$K'' v \frac{dv'}{dt} = W + l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Whence—

$$W = \tfrac{1}{2} K'' v \left(\frac{dv'}{dt} + \frac{dv}{dt}\right),$$

or since—

$$W = v c$$

we have—

$$K'' = \frac{2c}{\frac{dv'}{dt} + \frac{dv}{dt}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and—

$$l = \tfrac{1}{2} K'' v \left(\frac{dv'}{dt} - \frac{dv}{dt}\right)$$

and—

$$\frac{W}{l} = \frac{\frac{dv'}{dt} + \frac{dv}{dt}}{\frac{dv'}{dt} - \frac{dv}{dt}}$$

or—

$$l = W \frac{\frac{dv'}{dt} - \frac{dv}{dt}}{\frac{dv'}{dt} + \frac{dv}{dt}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

since the time interval here represented by dt will be constant for both curves we may write—

$$l = W \frac{dv' - dv}{dv' + dv} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

This gives the iron and friction losses as a function of the load on the machine, without any necessity for a determination of the constant K''.

It is to be noted that the value of K'' here employed has a different numerical value from K previously used, though the ratio between the two should be constant for a given armature current and excitation of the motor; it is, in fact, the ratio between the voltage generated in the armature with the given excitation and the speed of the shaft in revolutions per minute. One constant can thus be easily obtained from the other if this should be necessary.

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It is pointed out later that large errors may be introduced by the assumption that v is proportional to the speed, if the brushes are not accurately adjusted to the neutral position. For this reason the following retardation and acceleration curves were derived from measurements of speed independent of the voltage of the loaded motor.

From equation (5) we could obtain directly the mechanical efficiency of the whole apparatus, consisting of motor and flywheel. Thus—

$$\text{Mechanical efficiency} = \frac{W}{W + l} = \frac{1}{1 + \dfrac{dv' - dv}{dv' + dv}} \quad . \quad . \quad (6)$$

Since this contains the losses in the flywheel as well as those in the motor, we must make a correction in the values for dv and dv' if we wish to arrive at the efficiency of the motor alone.

This may be easily done.

If du is the increase in the height of the retardation curve of the flywheel alone, taken at the same speed and for the same time interval as dv and dv', then the fall in the retardation curve due to the motor losses alone will be $dv' - du$.

Similarly the change in the acceleration curve due to motor losses alone will be $dv + du$.

$$\text{Hence putting } dv' - du = \delta v'$$
$$\text{and } dv + du = \delta v$$

The mechanical efficiency of the motor becomes—

$$\text{Efficiency} = \frac{1}{1 + \dfrac{\delta v' - \delta v}{\delta v' + \delta v}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

All the quantities in this expression are directly obtained from a pair of acceleration and retardation curves of the motor and flywheel, and a retardation curve of the flywheel alone.

It is to be noted that this efficiency is calculated on the assumption of a constant C R drop in the armature. Any change in this will affect the value of W, and will alter the apparent value of the mechanical losses.

Equation (4) gives the value of the constant K″ in terms of the load. In this case, the constant is determined from the slope of the acceleration and retardation curves. The curves may consequently be said to form their own calibration, and the accuracy of the constant will depend simply on the accuracy with which these curves can be determined. This is a most important point, because one of the chief merits of the retardation methods of testing is, that all readings are of the simplest character, and may be made with a high degree of accuracy, the mean error being further reduced from the fact that the readings are plotted on curves before being used for calculation. It is consequently a very great advantage not to have to introduce other

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measurements, in which it is very difficult to ensure the exact conditions of the retardation run. Further, by eliminating the use of the constant entirely, the calculation is simplified in cases where only one pair of curves are taken.

It may be thought that to keep the armature current constant during the acceleration or retardation of the motor would be a matter of considerable difficulty. I have not found this to be so, partly because it is possible to use an ammeter with a very open scale, since only one value of the current is to be read. With a little practice, I found it possible to maintain the current so nearly constant that its maximum variation on either side of its correct value was not more than about ½ per cent., and its mean value must have differed by quite a small fraction of this from the normal. This accuracy was confirmed by the regularity with which the points fell on the plotted curves.

Experimental Determination of Stray-power Losses under Load.—One of the principal objects which I had in view in employing a flywheel to obtain load curves on a motor, was to see if it was possible by this method to obtain the value of the stray-power losses of a *loaded* machine, so as to compare them with the stray power at no load, which is measured comparatively easily by the several methods already summarised.

There has been some doubt as to the manner in which the stray-power losses varied with load,* and it therefore seemed of interest, if possible, to devise a means of ascertaining the amount of these losses as a function of the load, if this could be done in a fairly simple manner. It was this consideration which determined the form of the following tests, carried out with a flywheel; but I hope to be able to show that load acceleration curves taken with a flywheel may have a more general application.

The following results were obtained on a machine, the particulars of which are as follows:—

Makers, Lahmeyer Electrical Company, 3 B.H.P., 4 poles, 110 volts, 1,100 revs. per minute. Armature provided with two-circuit winding in 41 slots. Poles laminated. The brush rocker was intended for four sets of brushes, only two sets of which were employed during the experiments, in order to prevent disturbance by unequal current distribution in case of uneven brush resistance.

The motor was coupled by a crown clutch to a solid cast steel flywheel 22 ins. in diameter, 4½ ins. thick, and weighing about 480 lbs., which was independently mounted on roller bearings. The construction of the flywheel was not the most advantageous for the purpose, but the wheel happened to be available, and, when carefully trued up, answered the requirements excellently.

The method of procedure, as finally adopted, took the following form: After the motor and flywheel had been allowed to run for several hours to insure normal conditions, they were stopped and a

* See O. T. Blathy, *Electrician*, vol. 37, pp. 375, 474, 1896. Wm. Mordey, ibid., p. 446–7. H. J. Ryan, *Electrical World*, vol. 28, p. 272, 1896.

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liquid rheostat (a G. E. Company's theatre "dimmer") was inserted in the motor armature circuit. The motor was then made to run up to full speed with an absolutely constant armature current, while readings of speed and armature voltage were taken every 4 seconds during the acceleration. After running the set up a little beyond normal speed, the armature was disconnected from the supply and short-circuited across the water resistance. Similar readings were again taken during retardation, the current being kept at the same constant value as before.

In the particular series of results from which the curves (Figs. 4–8) have been plotted, acceleration and retardation curves were taken for

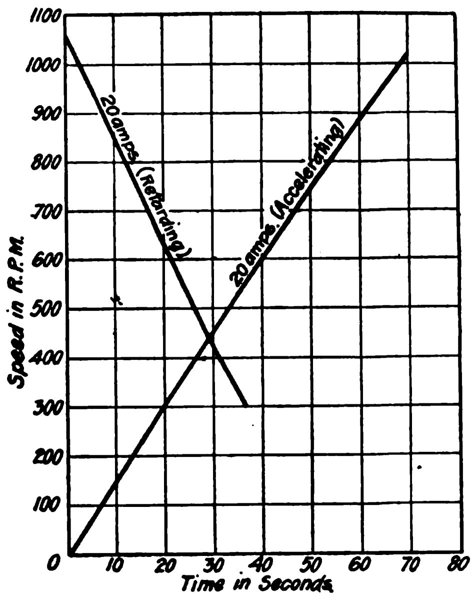

FIG. 4.—Acceleration and Retardation Curves under Load.

currents of 20, 15, and 10 amperes; while retardation curves were also taken for 5 and 0 amperes for which it was not possible to get acceleration curves.

Fig. 4 shows a typical pair of acceleration and retardation curves for 20 amperes.

The complete series of curves were plotted out to a large scale, and the watt curves, like those shown in Fig. 5, were worked out by using the calculated value of the constant K. In the earlier experiments this constant was determined by method 3 (page 442), but it was found that much closer and more consistent values were obtained by calculating the constant direct from the curves themselves. The importance of getting the constant with extreme accuracy is evident, when

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one considers that a small error in it will affect the apparent losses derived from a single acceleration or retardation curve to a large degree. Indeed, it was only after adopting the system of calculation given on page 448 that results which were entirely satisfactory and concordant could be obtained for the stray losses. By the earlier method of determination, the value of the constant could not be relied upon to within about 1 per cent. The later values agreed within 2 or 3 per thousand for any particular series of observations.

In Fig. 5 are drawn, in addition to the watt curves derived from the acceleration and retardation curves, the curves of terminal watts obtained by multiplying the observed terminal voltage by the armature current. In the accelerating curves, when the machine was operating as a motor, the terminal watts are higher than the watts spent in

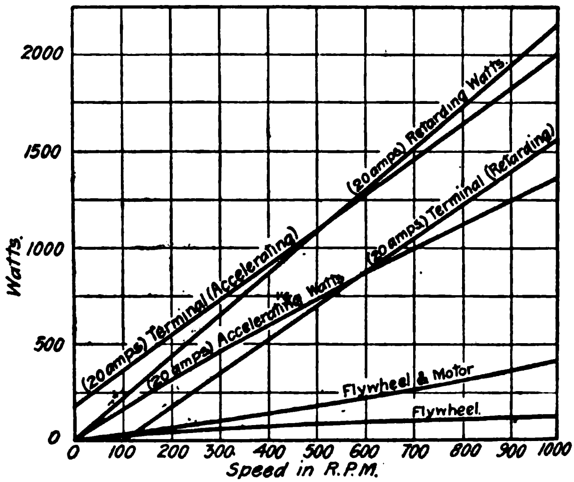

FIG. 5.—Watt Curves calculated from Fig. 4.

acceleration by the amount of the total losses in the system. In the case of the retarding curves, the reverse is the case. Lower, on the same figure, are shown the total no-load losses of motor and flywheel, and also the losses of the flywheel alone, both calculated from retardation curves. The difference between the two last curves represents the no-load stray losses of the motor.

In Fig. 6 the total motor losses are plotted for currents of 5, 10, 15, and 20 amperes on a base of speed. These losses were obtained, in the case of the acceleration curves, by subtracting from the terminal watts the watts actually producing acceleration of the flywheel, together with the watts lost in friction of the flywheel. For the retardation curves, the terminal watts and flywheel friction watts were subtracted from the total retarding watts. In each case the thick lines in Fig. 6 represent the losses obtained in this way from the "acceleration"

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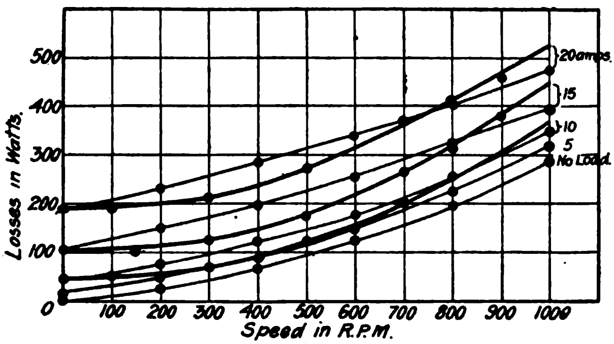
curves, while the thinner lines are from the results of retardation. It will be seen that the values for the losses in the machine when running at a certain speed with a particular armature current, appear when the machine is acting as a motor to be different from the losses when it acts as a generator. Further, the variation with speed of the losses in the two cases is not the same. This difference, which always appeared in my experiments, I am not able completely to account for. I think it likely that the peculiar difference between the curves is due to mechanical rather than to electrical causes. Possibly the roller bearings of the flywheel behave differently when starting from rest, and when slowing down from a higher speed. It may thus be that the thin (retardation) curves may represent the more uniform and more correct condition. The maximum divergence between a mean curve and the thinner lines does not exceed 25 watts.



Thick lines = Accelerating.
Thin lines = Retarding.

FIG. 6.—Losses obtained as difference between Calculated and Terminal Watts.

In the curves shown in Fig. 7, the *mean* of the values taken from Fig. 6 has been taken.

It may be objected that since the value of the watts is calculated by the use of a constant, on the assumption that the losses are the same when accelerating and retarding, the value of the constant will not be reliable if these losses are not identical. A calculation of the possible magnitude of this error shows it to be very small. Further, a small change in the magnitude of the constant will have the effect of altering, only slightly, the mean value obtained for the losses. It would raise one curve of each pair (Fig. 6) and lower the other, so affecting the mean value very little.

Indeed, any change in friction of the bearings due to a reversal of the direction in torque, would probably produce considerable errors in the value of the constant if this were determined in any other way. In the method adopted, we should largely compensate for these differences,

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In Fig. 7, the mean of the losses shown in the curves of Fig. 6 are plotted on a base of current, each of the five upper curves corresponding to a particular speed. Immediately below each curve of loss is shown a second curve, obtained by adding together the no-load, stray-power loss, and the C^2R loss calculated on the assumption of a constant resistance for the armature, brush contacts, etc. The ordinates between the two curves of each pair thus represents the increase in the stray power due to load.

Finally, Fig. 8 gives the increase in stray power obtained as shown in Fig. 7, as a function of speed for the four currents taken. It will

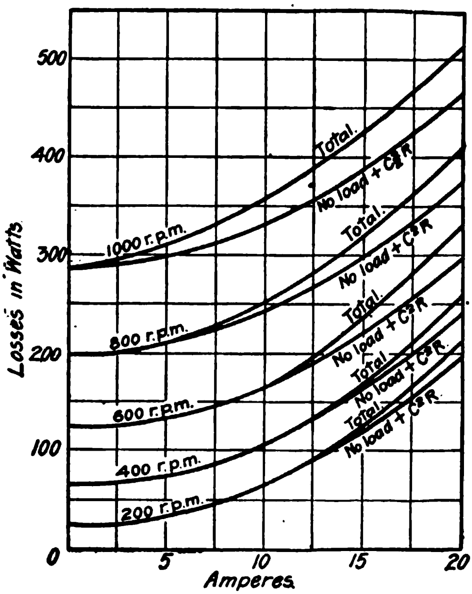

FIG. 7.—Comparison of Actual Losses with Losses Estimated from No-load Readings.

thus appear that the stray power increased with both speed and load. The total increase of stray-power losses at 20 amperes and 1,000 revolutions is seen to be about 50 watts or $\frac{50 \times 100}{2,000} = 2\frac{1}{2}$ per cent. of the total watts in the motor armature.

This increase appears at first sight to be extraordinarily high, but the greater part is accounted for by increase in brush contact resistance. The approximate change of brush-contact resistance with speed was measured by sending current from one brush to the other, situated on the same holder, while the machine (which had a 2-circuit winding) was being driven from the brushes of two

other holders. The changes of the resistance with speed were found to agree satisfactorily with the results of E. Arnold.*

The actual contact resistance decreases with current, but increases rapidly with speed. Thus there was over 100 per cent. increase in contact resistance above stationary value at 1,000 revolutions per minute with 20 amperes in the armature.

The brush-contact losses would not, of course, appear to be so large on a machine for higher voltage or of greater output.

Taking the average of a number of determinations, about $\frac{4}{5}$ of the losses shown in Fig. 8 were shown to be due to brush resistance. This leaves an increase in stray-power loss of about $\frac{1}{4}$ per cent of the output of the motor to be assigned to other causes.

My experiments have been confined to a single machine, so that a general conclusion cannot be drawn from the results. The result arrived at does, however, point to a definite, but small, increase in the

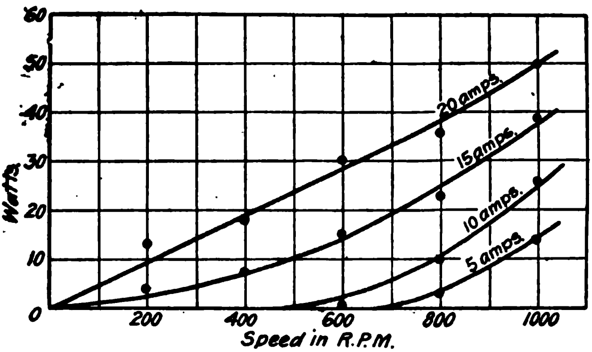

FIG. 8.—Increase of Actual Losses above Losses Estimated from No-load Readings.

stray-power losses with load in the case of the machine experimented on, apart from increased loss due to contact resistance.

Efficiency Test by Use of Separate Flywheel.—Apart from its special advantages for determining the losses, the use of a separate flywheel will give an accurate value for the efficiency of the motor at any load by an unusually rapid and simple test, which does not depend upon the accuracy of any instrument beyond a speed indicator and watch. This is seen from the equation (6) (page 449), where the efficiency appears as a function of the slopes of the acceleration and retardation curves, and is independent of any actual value of power, or of K″. If the ammeter and voltmeter which measure the electrical power supplied are not correctly calibrated, the efficiency obtained for the machine will still have the same value, if these instruments are used throughout, *i.e.*, in obtaining the losses in the flywheel as well as those in the motor.

* *Elektrotechnische Zeitschrift*, vol. 20, p. 5, 1899.

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As an example, referring to the two curves given in Fig. 4, at 800 revs. per min. and for a time interval of 12 secs. and back volts $= 74 \cdot 2$.

$$\delta v = 168 \text{ expressed in revs. per min.}$$

For the same *back volts*, $\delta v' = 260$.

$$W = 20 \times 74 \cdot 2 = 1{,}480 \text{ watts.}$$

Thus—

$$l = 1{,}480 \frac{260 - 168}{260 + 168} = 318 \text{ watts.}$$

The flywheel losses at this speed are 105 watts, leaving the motor, mechanical, and iron losses of 213 watts.

Hence efficiency of motor (exclusive of copper losses)—

$$= \frac{1{,}480}{1{,}480 + 213} = 87 \cdot 5 \text{ per cent.}$$

This gives total efficiency of motor at this load 75·2 per cent.

Use of Separate Flywheel in Test-Room.—It is on account of the simplicity and rapidity with which such results are obtained that I venture to call special attention to the use which might be made of a flywheel as part of the equipment of a test-room.

For machines of small size, the heat run in the test house is most suitably and economically carried out with the machines coupled in pairs, as for a Hopkinson test. As is well known, this test does not give good results for the efficiency of machines of less size than 10–15 k.w., since in calculating the efficiency from the observations, the losses in the two machines must be assumed equal, or else the efficiencies of the machines must be taken as equal. Neither of these assumptions is justified in the case of small machines when driving one another under load.

Further, it is not easy by the Hopkinson test, as carried out on small machines, to discover any defect or departure from the normal, which does not make itself evident by either sparking at the commutator or excessive heating of some part. It is therefore suggested that after the usual heat run has been taken, such machines should be coupled to the flywheel and an acceleration curve taken, at constant full-load current. The necessary connections are of the simplest character, and the time required for the observations would only be a couple of minutes.

The characteristics and frictional losses of the flywheel would be known, and it would, therefore, be easy at any time to calculate the efficiency of the motor from the acceleration curve. I am aware that the exact efficiency of a motor is not a quantity which it is generally of great importance to ascertain. It seems to me, however, that when taken in this way on a single flywheel, the actual acceleration curves would form a valuable record, and would at once bring out any departure from the standard due to abnormal losses, incorrect field strength, wrong brush adjustment, etc. Since all curves would be taken on the

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same flywheel, they could be directly compared with standard curves without any further calculation being made. As pointed out later, the effect of the inertia of the motor armature in altering the constant used in calculations based on the retardation curves might usually be neglected. The test would be conducted as outlined on page 446.

Size of Flywheel.—It will now be of interest to consider the practicable limits of size of motor for which the test just outlined is capable of application.

Let us take as an example a flywheel about 5 ft. diameter with a rim 6 ins. × 6 ins., and see what size of motor would be required to accelerate this up to a full speed of 1,000 revs. per min., allowing 1 min. for the time of acceleration.

I have supposed the wheel to be built up of a steel disc ¾ in. thick * and provided with a wrought steel flange consisting of a ring of rectangular section riveted at the circumference of the disc on each side. Each of these rings is taken as 6 ins. × 3 ins. in section, the larger dimensions being measured radially.

With a mean diameter of the flange of 5 ft., and allowing a maximum speed of 300 ft. per second, about the limit of modern turbo-alternators, this wheel would have a maximum safe speed of, say, 1,100 revs. per minute.

The approximate weight of this wheel would be 2,690 lbs. and its moment of inertia, say, 14,720 lb. ft.^{2}.

The energy of rotation of the wheel—

$$= W = \frac{\frac{1}{2} I (2 \pi n)^2}{116,000} = \frac{I n^2}{5,800} \text{ ft.-lbs.} \quad \ldots\ldots \quad (1)$$

where I = moment of inertia in lb. ft.^{2}

n = revs. per min.

The work done by the motor in bringing the flywheel up to the full speed of n revolutions per minute, while exerting its full-load torque, will be equal to—

(average H.P. exerted by motor) × (time of acceleration)

$$= \frac{33,000 \text{ H.P.} \times t}{2} \text{ ft.-lbs.} \quad \ldots\ldots \quad (2)$$

where t = time of acceleration in minutes; H.P. = capacity of motor. Equating (1) and (2), we obtain the relation between the size of motor and the quantities depending on the flywheel thus—

$$\text{H.P.} = \frac{I n^2}{5,800} \times \frac{2}{33,000 \, t} \quad \ldots\ldots \quad (3)$$

* This disc would require to be reinforced near the shaft, in order to withstand the radial stresses to which it would be subjected, but for the purpose in hand this is not of importance.

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Putting in the full speed of motor $= n = 1{,}000$ and the time of acceleration 1 minute* and substituting the calculated value of I, we obtain—

$$\text{H.P.} = \frac{14{,}700 \times 1{,}000{,}000 \times 2}{5{,}800 \times 33{,}000 \times 1} = 150 \text{ H.P.}$$

as the largest size of motor which could be tested on the assumed flywheel under the assumed conditions.

It is, of course, not suggested that it would be convenient to carry out such a test on a motor of this size. The figures show, however, that as regards the mechanics of the problem, a wheel considerably smaller than that of an ordinary 25-H.P. gas engine would have sufficient inertia to provide the load for fairly large motors.

In most cases it would probably be unnecessary to make any correction for the change of moment of inertia due to the mass of the motor armature. Thus, the armature of a 4-pole motor giving 10 H.P. at 1,000 revs. per min. would be of the order of 15 lb. ft.^{2}, which is about $\frac{1}{1{,}000}$ of the value of the hypothetical flywheel given above. It would be very easy to keep a list of constants to be used for any flywheel when coupled to motors of given armature diameters, since small divergencies in the size of armature would not be detected at all.

A very rough estimate of the moment of inertia of the armature would, in any case, be quite accurate enough.

Determination of Armature Drop.—If while the motor is driving the flywheel, the armature circuit is suddenly opened, the terminal voltage will at once fall to the voltage which the machine will have when working as a dynamo on open circuit at the speed at which it is then running. The inertia of the flywheel maintains the speed sufficiently constant for the drop of voltage on opening the circuit to be easily observed.

If the armature circuit is opened while the machine is being driven by the flywheel and while it is then acting as a generator, the terminal voltage rises, by an amount equal to the armature drop, to its no-load value. It is thus easy to determine very exactly the armature drop due to any current, and also to find its amount for any brush position and speed.

Armature reactions due to displacement of the brushes from their neutral position will tend to increase the drop of the machine whether running as dynamo or motor, or to decrease it in both cases. It would consequently be natural to expect that the same values for the armature drop would be obtained from the machine when working either as generator or motor with a fixed brush position, unless the brush displacement from the neutral position were considerable.

In taking the retardation curves, it was therefore thought at first that in order to obtain the speeds of the motor while retarding or accelerating, it would be sufficient to obtain the armature drop at

* The time of acceleration will actually be more than 1 minute under the conditions assumed, owing to the frictional resistances.

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several speeds for each value of the constant current, and, after subtracting this drop from the terminal voltage, or adding it to the terminal voltage, to take the resulting voltage as being proportional to the speed.

This was afterwards found not to be admissible in the case of the motor experimented upon, as the strengthening of the main field when the machine acted as a motor with brushes displaced slightly backwards was not equal to the weakening effect of the same armature reaction ampere-turns when the machine was running as a generator. This effect was probably specially marked in the case of the machine used for these experiments, because of the high saturation of the pole-tips. It was further found that even with the brushes set in the neutral position it was not possible to depend on obtaining exactly the

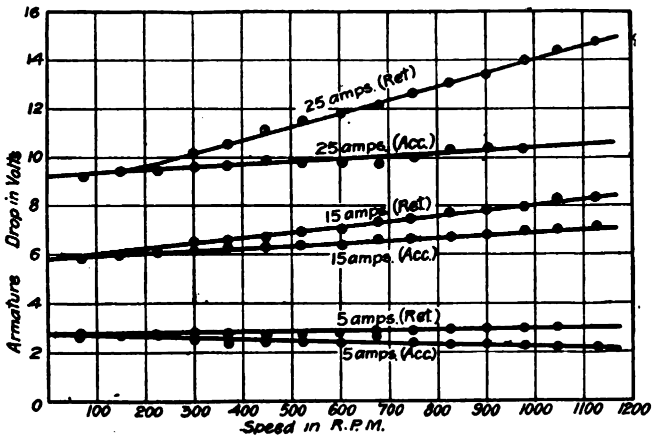

FIG. 9.—Comparison of Values of Armature Drop for Machine acting as Generator and Motor.

same value of the armature reaction drop when accelerating and retarding.

The considerable divergence from proportionality between speed and terminal voltage is shown on the curves given in Fig. 9, where the armature drop is shown, as measured by opening the armature circuit at various speeds. The brushes in this case had a backward displacement of about 1½ segments of the commutator. With a forward lead of the same amount, the upper (retarding) curves became practically horizontal and the accelerating curves sloped downwards, making about the same angle with the retarding curves as those shown in Fig. 9.

As a result of this effect, I decided in my experiments to measure the speeds by using a small auxiliary generator having constant excitation coupled to the shaft of the flywheel.

The curves shown in Fig. 9 are not without interest, as showing the

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extent to which the armature drop in a machine may depend on the direction of the armature current. They also show that it would not be correct in such a case to assume the volts generated in the armature to vary in simple proportion with the speed—a point to be noted in connection with the equations given on page 448.

It may be well to enumerate the special points mentioned above in connection with the use of a separate flywheel employed as an inertia load.

1. By using a flywheel, a motor may be tested under load, the output being accurately determined by observations of speed and time only.
2. Acceleration curves taken in this way on the same flywheel might form a direct check on the satisfactory construction and adjustment of motors without further calculation.
3. The use of combined acceleration and retardation curves forms the most satisfactory method of determining the "constant" of the rotating system.
4. By the use of these curves the losses or efficiency may be determined without evaluating the constant.
5. The employment of a flywheel affords a means of determining the stray-power losses of a loaded machine.
6. The armature "drop" is readily determined on the machine when acting either as generator or motor.

PART II.

Alternating-Current Induction Motors.

Comparatively little information has been published in this country on the experimental determination and separation of the losses in induction motors, although a considerable number of communications on the subject have appeared in various foreign journals.

It may, therefore, serve a useful purpose to collect together some of the most important of the methods which have been suggested, and to point out to what extent they may be expected to give the desired results.

With a view to assisting in the comparison of the various methods, several of them were tried under as nearly as possible identical conditions on a 5-H.P. 6-pole induction motor recently supplied to the School of Technology, Manchester, by Messrs. Siemens Bros. & Co., and the results are shown in the form of curves.

Losses to be Measured.—The various losses to be measured consist of :—

(*a*) Copper losses in stator and rotor conductors.
(*b*) Friction and windage losses.
(*c*) The stator iron magnetising losses.

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(*d*) Rotor eddy-current losses.
(*e*) Rotor hysteresis losses.
(*f*) Pulsation losses due to the rapid changes in flux distribution in the teeth of the stator and rotor.
(*g*) Additional losses which are due to increase of load.

Nature of Losses.—(*a*) Copper losses. The resistance of the conductors employed in the calculation of the copper losses is usually measured by direct current. This is known not to give strictly correct values for the resistance of the stator conductors, particularly in the case of conductors of large section, owing to the distribution of an alternating current not being uniform throughout the section of the conductor. For the correction to be made for this see M. B. Field, *Journal, Institution of Electrical Engineers*, vol. 37, p. 83.

(*b*) Friction and windage losses. The variable element in these losses is usually due to change in friction of the bearings on account of change of temperature or unequal circulation of the oil. As pointed out earlier in this paper, change in load may be expected not to produce any variation in the losses of properly lubricated bearings. An apparent increase of friction may be found to occur in the case of imperfectly centred rotors, although except in extreme cases, the increased losses due to this cause are probably to be ascribed to increased iron losses, rather than to friction losses. Also, unsymmetrical conditions about an axis through the centre of the stator perpendicular to the shaft may produce frictional losses due to end thrust which will not be independent of the load.

The friction losses appear as additional load on the motor shaft.

(*c*) The stator magnetising losses consist of the usual two components due to hysteresis and eddy currents. They are here classed together, since they are usually determined together. They are dependent only on the induction (*i.e.*, on the terminal voltage) and on the frequency, and may therefore be taken to be independent of load.

These losses appear in the form of additional power supplied to the stator.

(*d*) The rotor eddy-current losses in the teeth (exclusive of the tips which are affected by the pulsation losses, *f*), and the body of the stampings depend on the frequency of the alternating flux in the rotor. They will increase with the slip and practically disappear at synchronism and are consequently small at normal loads.

These losses must, of course, be supplied from the stator, but will reappear in part as additional output by the rotor, the efficiency of this conversion of power depending on the conductivity of the metal in which the eddy currents are formed.

(*e*) The rotor hysteresis loss is practically constant in amount when estimated as power supplied to the stator. This power is, however, partly converted into useful output. Since the portion thus usefully added to the output of the motor varies inversely with the

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slip, it is perhaps hardly correct to say that the "loss" due to hysteresis is constant.

The true losses due to hysteresis in the rotor core are due to the cyclical change in magnetisation of the core by the stator magnetising currents. If the rotor is stationary, the losses thus produced will be in every way similar to the hysteresis losses due to the same cause in the stator. They will, therefore, be directly proportional to the frequency of the applied voltage and to the hysteresis constant of the material. The hysteresis losses appear, consequently, in the form of additional energy current supplied at the stator terminals. The fact that the hysteresis of the rotor iron causes the pole induced in the rotor to lag behind the stator flux, which induces it, gives rise to a torque between the rotor and the rotating field. The conditions may be pictured as a revolving field formed in the stator followed by a polarity in the rotor iron, revolving at the same speed, but displaced behind the stator field, by a small constant angle, due to residual magnetism, which depends only on the hysteresis constant η and which is independent of the speed of rotation. This angle has been called the angle of hysteretic lag. The component of the attraction between the poles of the main field and those in the rotor iron, which is in a tangential direction, will produce a torque on the rotor. This torque, combined with the torque due to eddy currents in the rotor core when the slip is large, may be sufficient to produce a rotation of the rotor when open circuited. The special point to be noticed about this effect, is that the hysteresis torque is practically independent of the speed of the rotor (unlike the torque due to the eddy currents, which is proportional to the slip) and depends only on the constant η, that is on the area of the hysteresis loop formed by the rotating flux in the rotor iron.

When the rotor is stationary, as assumed at first, the whole of the power supplied to the stator winding on account of rotor hysteresis will be converted into heat in the rotor.

This power is given by the usual formula :—

$$W = \eta B^{1.6} \sim \quad \ldots\ldots\ldots \quad (1)$$

if we assume the Steinmetz index of 1·6.

Where—

$W =$ watts per cub. cm.

$\eta =$ Steinmetz's hysteresis coefficient.

$\sim =$ frequency of the supply voltage.

If the rotor rotates, useful work is done by the torque due to hysteresis. The power thus usefully exerted will be equal to the hysteresis torque multiplied by the angular velocity of the motor shaft.

The power supplied to the stator is still the same as before, but is now only partly spent in heating the rotor iron, and is partially converted into mechanical energy. In fact, we can re-write the expression for the hysteresis loss in equation (1) so as to show the two parts, by substituting the value—

$$\sim = S + np.$$

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Where—

S = slip in cycles per sec.
n = revs. per sec. of rotor.
p = No. of pairs of poles.

Thus—

$$W = \eta B^{1 \cdot 6} (S + n p) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The factor $\eta B^{1\cdot 6} n p$ gives the power converted into mechanical energy, while the factor $\eta B^{1\cdot 6} S$ gives the portion transformed into heat in the rotor core due to molecular magnetic friction.

If the motor is driven by some external means, and its speed is made to increase up to synchronism, the whole of the power given to the stator on account of rotor hysteresis, is converted into mechanical energy, and there is then no loss due to molecular friction, since iron and field revolve together without change of magnetisation in the core. On passing above the speed of synchronism, the rotor iron moves relatively to the rotating field, but in an opposite direction, so that the rotating field now lags behind the polarity formed in the rotor iron by the angle of hysteretic lag, which will have the same value as before. This results in a reversal of the torque exerted by the residual magnetism. At the same time, a reversal takes place in the sign of the watts supplied to the stator, on account of the hysteresis losses. In fact, the motor will now deliver back to the line the same amount of power which, below synchronism, was supplied from it, and the power which is mechanically supplied to the rotor shaft will be now converted into electrical energy, in virtue of the hysteresis, and given out at the stator terminals.

The power thus given back to the line will be constant at all speeds above synchronism, while the mechanical power, driving the rotor, will be equal to this at a speed immediately above synchronism, and will increase in direct proportion to the negative slip at higher speeds, the increase of power being spent in magnetic molecular friction in the motor core.

The sudden reversal of the hysteresis torque of synchronism may be employed for separating this loss from other no-load losses as described on page 473.

(*f*) The losses which may be briefly called the "pulsation losses," are due to the very rapid changes of flux distribution which occur at the tips of the teeth of both stator and rotor. When a stator and rotor tooth are exactly opposite to one another, the flux passing from the stator to the rotor at this point in the circumference of the rotor will pass mainly across the air-gap from tooth to tooth, and will be symmetrically distributed over the tips of both teeth. As the rotor tooth moves, the flux will be dragged forward, so as to be more concentrated at those edges of both stator and rotor teeth which are leaving one another. As the next rotor tooth comes under the stator tooth, the flux jumps back so as to cross between the new pair of teeth. We have, in fact, a "drag" and a "flash" as described in the case of

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alternators by Mr. G. W. Worrall in his recent papers before this Section. Put in another way, each tooth will carry alternately a strong and a much weaker flux according as it is situated opposite to a tooth or a slot.

In the case of a 3-phase stator, with two slots per phase per pole, there will be twelve slots per pole-pair, consequently when running at synchronous speed on a 50-$\sim$ circuit, each tooth of the rotor would be subjected to a varying flux having a frequency of $50 \times 12 = 600$ periods per second. The intensity of the variation will be greater with open slots, but even with closed slots considerable variation has been found to occur. It is easy to see that the larger the air-gap the more evenly distributed will be the flux in the air-gap, and the smaller will be the losses due to the pulsation effect. Pulsation will occur in the teeth of both stator and rotor, and give rise to both hysteresis and eddy currents in the teeth, the comparatively large value of which is due to the high frequency of the flux variation to which they are due.

Evidently the pulsation losses will depend on the absolute speed of the rotor, and will decrease with increasing slip. They will always have a retarding effect on the rotor, and will resemble the frictional losses as regards their effect on both input and output of the motor; their resemblance to the frictional losses has indeed led to their inclusion in the assumed value of the latter.*

(*g*) In addition to the foregoing there are losses which depend only on the load, the exact nature of which is still not clearly known.

METHODS FOR DETERMINATION OF FRICTION LOSSES.

1. *By Auxiliary Driving Motor.*—This method is the well-known one for determining the losses in one machine by driving it by means of a motor, and afterwards subtracting the copper and no-load losses of the motor from the total driving power to obtain the losses in the machine under test. When employed for determining the friction losses in the unexcited induction motor, no further remarks need be made than those given on page 439.

When the stator of the induction motor is connected to the supply and the rotor is open, separation of the various iron losses is possible, as discussed later.

2. *By Decreasing Stator Volts.*—This is analogous to the method already discussed in connection with direct-current motors (see page 2). In the case of the induction motor the stator volts are gradually reduced down to the limit of stable running. A curve is then plotted showing the stator watts supplied on a base of terminal voltage, see Fig. 10. When continued, this curve cuts the axis corresponding to zero voltage at a height representing the watts required to overcome losses which are independent of the magnetic field, *i.e.*, the friction losses.

Although it is possible with care to get fairly consistent results by

* See especially J. Hissink, *Elektrotechnische Zeitschrift*, vol. 22, p. 226, 1901.

this method when applied to induction motors, there are several practical difficulties connected with the measurements.

First, although the speed of the motor remains practically constant over the greater part of the range of voltages, at the lowest readings the slip may be 10–15 per cent. or more. The actual friction losses would thus be those corresponding to a speed of about 10 per cent. below the normal.

On the other hand, an increase in slip will increase the rotor iron losses, which will in consequence not decrease uniformly with the voltage. The two actions just mentioned will tend to neutralise one another, and this may account for the good agreement with the actual values often given by this test, while explaining the want of agreement

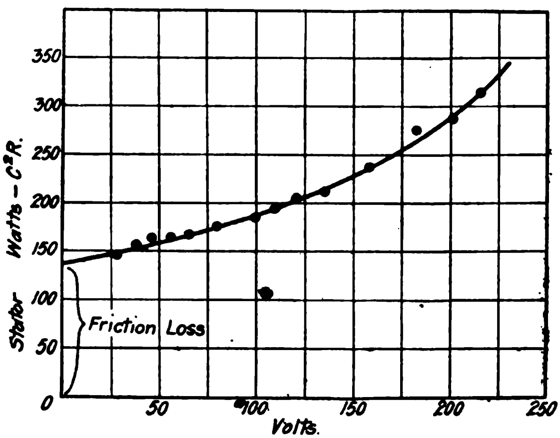

FIG. 10.—Determination of Friction Losses.

found in other cases, where the two errors compensate one another less completely.

A serious source of error may be found in the uncertainty as to the correct point of intersection of the curve with the vertical axis. This is often accentuated by the fact that the motor may run at a very much greater slip than the normal, taking a much less power, when the point of minimum voltage is approached. It is thus possible to get a series of points on a curve much lower than the true one, and to make a large error in the value of the friction. Unless the minimum voltage, and consequently this unstable condition, is reached, it will be difficult to find the correct position for the continuation of the curve.

Another practical difficulty is the very low power factor at which the readings have to be taken, and the consequent liability to errors in the wattmeter readings.

Since the current supplied, and consequently the copper losses, do not decrease towards a zero point at zero induction, the copper losses

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should be subtracted before the watt curve is plotted if accurate results are to be obtained.

The suggestion that the watts should be plotted on a base of $(\text{volts})^2$ has already been alluded to (page 438).

It will be seen that the objections to this method are in the nature of difficulties to be met with in its practical application. The losses finally obtained, supposing these difficulties to be overcome, are the true friction losses of the motor. The uncertainty of opinion recently existing on this point (and also perhaps the doubtful accuracy of the results of the experiment due to the causes enumerated above) is brought out in a rather amusing manner by the correspondence carried on in connection with Benischke's method of determining the friction losses (see method 4 below). In support of Benischke's method, which had been severely criticised in the press, Professor Peukert published,* in 1903, a series of tests in which he found that the friction losses as determined on a number of motors by the Benischke method and by the one just described were in close agreement. The following year Dr. Benischke himself published a book (" Die Asynchronen Drehstrom-motoren," Vieweg und Sohn, 1904), in which he gives a numerical example to show that the voltage variation test gave far too low values for the friction loss (53 watts in his example), and that his own method gave a considerably higher value (88 watts), which he stated to be the correct one.

That the results of the Benischke method are not the true friction losses is pointed out later on in describing that test.

3. *Method of Blanc.*—A method depending on a different principle was suggested by F. Blanc in 1900.†

The torque of an induction motor may be stated in two ways, viz., in terms of the rotor copper losses or in terms of the mechanical output. Thus for a 3-phase motor—

$$T = \frac{3\,C_2^2\,r_2\,p}{2\,\pi\,s} \qquad \qquad (1)$$

also—

$$T = \frac{W}{2\,\pi\,n} \qquad \qquad (2)$$

Where T = total torque in dyne cm.
W = total mechanical output in watts, including power spent in bearing friction, etc.
C_2 = rotor current per phase.
r_2 = rotor resistance per phase.
p = No. of pairs of poles of stator winding.
s = slip in cycles per second.
n = revs. per second of shaft.

Equating the two expressions for torque—

$$\frac{3\,C_2^2\,r_2\,p}{s} = \frac{W}{n} \qquad \qquad (3)$$

* *Elektrotechnische Zeitschrift*, vol. 24, p. 662, 1903. † *Ibid.*, vol. 21, p. 131, 1900.

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When running light, W consists entirely of power spent in overcoming the frictional and other losses which oppose the rotation of the shaft. Consequently, putting n_o and s_o for the speed and slip at no load, we obtain these losses from the relation—

$$W_o = \frac{n_o \, 3 \, C_2^2 \, r_2 \, p}{s_o},$$

or, putting—

$$n_o = \frac{\sim - s_o}{p}$$

$$W_o = \frac{\sim - s_o}{s_o} \, 3 \, C_2^2 \, r_2.$$

The determination of the no-load losses is thus reduced to a measurement of the slip and of the rotor current and resistance.

The rotor resistance can be measured with a potentiometer or double bridge, care being taken to include all connections to the starting resistance, etc., as under working conditions. The rotor current, on the other hand, is not easy to measure when the motor runs light, owing to its slow periodicity.

Instead of the quantity $C_2^2 \, r_2$ we may, for convenience in measurement, put—

$$\frac{e_2^2}{r_2},$$

where e_2 represents the voltage induced per phase in the rotor winding. At the low slip which the motor has when running light, Blanc assumes that the effect of self-induction may be considered negligible, so that the rotor impedance can be assumed to consist of resistance only. He also points out how any error due to this assumption may be corrected. The value of e_2 is obtained experimentally by direct measurement (when the motor is stationary) on a voltmeter connected to the terminals of the rotor winding, the normal voltage being applied to the stator. The value of e_2 is then obtained by moving the rotor into the position giving a maximum value of the induced voltage.

The final form of the expression for the no-load losses overcome by the rotor becomes—

$$W_o = \frac{\sim - s_o}{s_o} \cdot \frac{3}{r_2} \cdot \left(\frac{e_2 \cdot s_o}{\sim}\right)^2 = s_o \frac{\sim - s_o}{\sim^2} \cdot \frac{3 \, e_2^2}{r_2},$$

where e_2 is the stationary measured voltage.

Except for the uncertainty of the resistance of brush contacts on slip rings and starting rheostat, this method is found to give in a fairly simple manner reliable and consistent results for the losses overcome by the rotor. It is, however, not correct to take these losses as being the true friction losses.

Several experimenters have pointed out that both in this method of determining the friction losses and in the one to be next described,

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the negative torque due to friction will be partly overcome by the positive torque due to rotor hysteresis. It thus follows that the actual losses measured will be smaller than the true frictional loss by that portion of the hysteresis loss which is converted into mechanical energy, *i.e.*, by the watts expressed by the symbols $\eta\ B^{1.6}\ n\ \phi$ on page 462.

It does not, however, appear to have been generally recognised that the hysteresis losses are not the only ones affecting the results. The pulsation losses in the tips or bridges of the teeth will also appear as a retarding force on the rotor, and will consequently increase the observed value of the friction losses by the full amount of the losses. Thus if—

W_F = friction losses.
W_H = rotor hysteresis losses, which are practically all transformed to mechanical torque at this speed.
W_P = pulsation loss.

The result of the determination will not be the friction losses only, but will be—

$$W = W_F + W_P - W_H.$$

This method of determination has the disadvantage that it is only applicable to motors with wound rotors.

4. *Benischke's Method.*—A method somewhat similar to the last in principle is that due to Dr. G. Benischke,* which depends on the fact that for small values of the slip, the total torque of the rotor varies in direct proportion to the slip. The slip of the motor is measured at no load and at one or two loads slightly above no load. A curve is then plotted on a base of torque—or more conveniently watts—with slip as ordinates (see Fig. 11). Joining the points thus obtained by a straight line, and continuing this line backwards to cut the horizontal axis at a point corresponding to zero slip, the distance of this point to the left of zero output will be the power exerted by the rotor in overcoming frictional and other resistances to its rotation.

The actual power measured in this case, as in the last, is really the friction + pulsation losses — the mechanically converted hysteresis loss.

This method is fairly easy to carry out if a convenient method of applying a small load to the motor is available. It is equally applicable to motors with wound and squirrel-cage rotors. Benischke originally employed a band and weights hung over the motor pulley. A far more satisfactory and more easily regulated form of brake is one of the eddy-current type, such as that described by Messrs. Morris and Lister.† It is to be noted that the load applied must be very small, as the readings will otherwise not give a straight line when plotted. Both of the above methods (3) and (4) may be fairly easily carried

* *Elektrotechnische Zeitschrift*, vol. 22, p. 698, 1901.
† *Journal, Institution of Electrical Engineers*, vol. 35, p. 445.

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out, and the measurements are such as can be accurately made without difficulty. As originally proposed, they both suffer from the disadvantage that what is measured is not the frictional losses of the motor. This is shown in the present case by comparing the value of the "friction" loss in Fig. 11 (= 198 watts) with the true friction loss (= 136) as obtained from the curves shown in Figs. 10 and 13.

A very simple application of the retardation method of measurement may, however, be employed to complete the determination of the friction losses attempted by the authors of these tests.

If the induction motor be run up to full speed in the usual way, and, when running light at full speed, if the rotor circuit be opened,

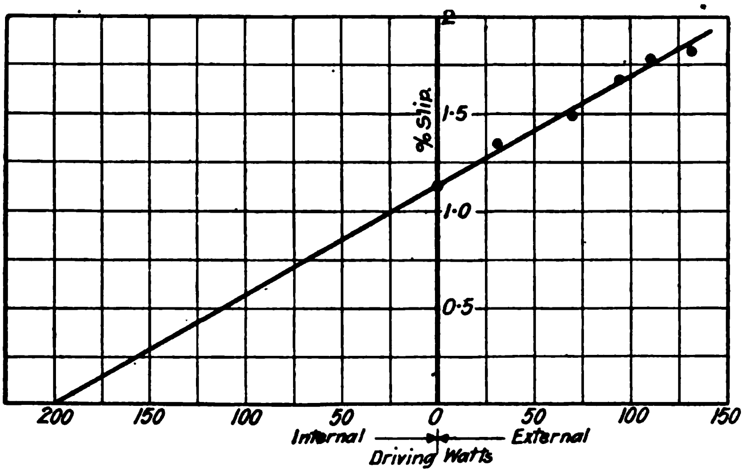

FIG. 11.—Determination of Losses by Benischke's Method.

the rotor will slow down and gradually come to rest. The retarding forces will be those due to friction and magnetic pulsation in the teeth, while the rotor hysteresis will tend to accelerate the rotor and prolong the time of coming to rest. During the early part of the retardation these will be the only forces to be considered. As the slip becomes large, eddy currents will be formed in the rotor core and conductors which will produce a diminution of the effective retarding forces. If a retardation curve is plotted with time measured horizontally, and speed vertically, from observations made on the motor while retarding as described, a tangent drawn to the curve near the point of maximum speed will make an angle α with the horizontal axis such that its tangent, $\frac{ds}{dt}$, is proportional to the losses—

$$W + W_P - W_H.$$

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Now suppose that another retardation curve is taken with the stator open circuited. In this case retardation will be due to frictional losses only, and a tangent to the second curve $\frac{ds'}{dt}$ at a point corresponding to the same speed as the first tangent will be proportional to the friction watts—

$$W_F.$$

As the heights of the points from which both tangents are drawn are taken to be the same, the subtangents will be inversely proportional to

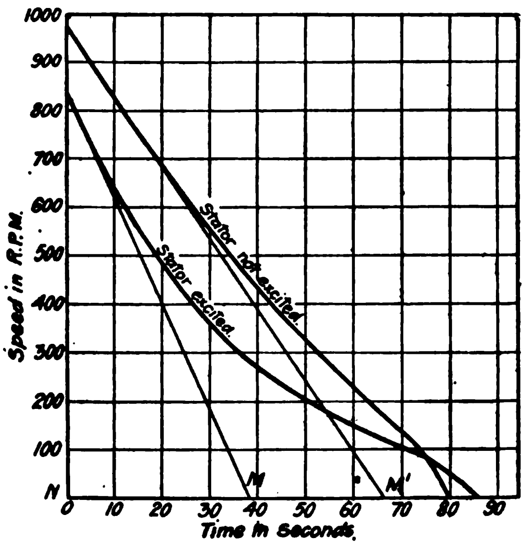

FIG. 12.—Retardation Curves with Stator Excited and Unexcited.

the retarding watts in the two cases, and we have the relation (see Fig. 12)—

$$\frac{N\,M}{N\,M'} = \frac{W_F}{W_F + W_P - W_H}$$

or—

$$W_F = \frac{N\,M}{N\,M'}\left(W_F + W_P - W_H\right)$$

from which the true friction watts are determined from the value of $(W_F + W_P - W_H)$ obtained in either of the tests described (Nos. (3) and (4)).

In taking the two retardation curves, since only the *ratio* of the initial slopes of the curves is required, it is immaterial how the readings are taken, so long as the two curves are strictly comparable. Also only a few readings are required near the maximum speed. With

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motors of fairly large size, it would be sufficient to observe the times taken to retard by a certain amount after opening in one case the rotor, and in the other case the stator circuit.

The two retardation curves shown in Fig. 12 were taken on the same motor as the other tests. Unfortunately, however, the ratio $\frac{N M}{N M'}$—which in this case is 0·577—cannot be employed for correcting the results obtained in the Benischke test, as the slip-ring brushes had to be lifted in order to obtain the curves. The brush friction was so great that satisfactory readings for the retardation could not be obtained without removing them. The ratio $\frac{N M}{N M'}$, does not, therefore, apply to the same value of the friction as that shown in the other curves.

The effect of eddy currents in causing the curves to approach one another and then cross is well shown in Fig. 12.

5. *By Opening Rotor Circuit.*—We may next refer to a very simple method which has been much used for measuring approximately the friction losses. The watts supplied to the stator of the motor when running light are observed. The rotor circuit is then opened and the watts are observed immediately after, before the motor has had time to slow down appreciably. The difference between the two wattmeter readings, after correction for the C^2R losses, is taken to be the friction losses of the motor. This again is not a correct assumption for the following reason. Before the opening of the rotor circuit the power supplied consists, in addition to the copper losses, of the stator iron losses, and rotor friction, hysteresis and pulsation losses. After opening the rotor circuit, the rotor is no longer driven by the stator, except in virtue of the rotor hysteresis. Thus, while the rotor hysteresis watts supplied to the stator remain the same as before, the difference in the wattmeter readings is the sum of the rotor retarding effects, *i.e.*, the sum of the friction and pulsation losses. The power measured by this method is therefore again not the true friction watts, but is greater by the amount of the pulsation losses.

6. *Retardation Curves.*—Retardation methods for measuring losses, which are so well adapted for measurements on direct-current and synchronous alternating machines, have only a limited application in the case of induction motors. The simplicity of the direct-current measurements is here rendered impossible by the fact that excitation and driving current are both supplied to the same terminals, and one cannot be varied or even measured independently of the other. Even with the rotor open, eddy currents and rotor hysteresis produce the result that an uncertain driving power is supplied to the rotor from the mains, in addition to the excitation loss. It thus becomes impossible to find the constant K connecting the rate of retardation with the power required to overcome the retarding forces in the manner in which this is carried out for a continuous-current machine.

In order to obtain the relation between retarding watts and retarda-

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tion, Bragstad and La Cour* have suggested supplying the excitation losses entirely to the rotor in the form of direct current supplied to two of the slip rings, while the motor is made to run synchronously. The machine then operates as a synchronous motor with rotating poles excited with continuous current, and the alternating supply provides the armature currents producing the driving power.

The power supplied to the stator to maintain the rotation at any speed is then measured and compared with the slope of the retardation curve obtained by allowing the motor to retard with the same continuous-current excitation, but with no alternating-current supply, in order to obtain the constant as described on page 442. After obtaining the constant in this manner, the friction losses are obtained from a retardation curve taken on the motor when retarding from full speed entirely without excitation.

In order that the whole of the magnetising power may be supplied by the rotor excitation, the armature reactions in the stator must be a minimum, and must not tend to strengthen or weaken the revolving field of the rotor. This necessitates that the stator voltage shall be adjusted so that the stator current comes into coincidence of phase with the induced voltage in its conductors. This condition can only be obtained by trial, the terminal voltage being varied until the power factor of the supply circuit is a maximum. The nature of the magnetic circuit causes the reactance of the stator winding to be relatively high, and the power factor of the primary circuit does not become unity. There will thus always be some alternating flux maintained by the stator, and there must be a certain amount of iron loss in addition to the driving power included in the measured input. This will have the effect of making the constant slightly larger than its true value.

The great difficulty in determining the constant accurately by this method is shown by the variation in the values actually determined. These differed from one another by amounts up to about 2 per cent. Although the mean was taken of a considerable number of values, it is evident that great accuracy was not obtainable.

A more accurate method of obtaining the constant would be to calculate it from the moment of inertia of the rotating parts, obtained experimentally by purely mechanical means (see page 442).

This method of measurement by taking retardation curves is again referred to in connection with the determination of the iron losses, for which purpose it was proposed.

The simplest method of employing the retardation method for determining the friction losses is to carry out the experiment with the induction motor coupled to a continuous-current motor, the two machines being allowed to retard together. The test is then exactly as detailed in the first part of this paper (see page 441). The friction losses of the continuous-current motor must be separately determined and subtracted. It is evident that this is at best a cumbrous experi-

* *Elektrotechnische Zeitschrift*, vol. 24, p. 34, 1903; *Zeitschrift für Elektrotechnik*, vol. 23, p. 381, 1905; see also J. L. La Cour, Leerlauf und Kurzschluss-Versuch, Vieweg & Sohn, Braunschweig, 1904.

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ment, and the retardation method must be considered as not well adapted for the purpose.

A method which I believe is due to Mr. Cramp, by which very accurate values for the no-load friction coefficient may be obtained, is to wind a string round the shaft of the motor and pass the free end over a light pulley at a considerable height from the ground. Weights are then attached to the end of the string until by repeated trial the correct weight is found. This weight is such that, when started downwards, it is just able to maintain rotation of the motor shaft without acceleration. The uniformity of speed is ascertained by noting the time intervals taken by the weight to fall past two equally spaced marks. The friction torque is thus found directly in terms of the weight and the radius at which the weight acts on the rotor shaft.

METHODS FOR DETERMINATION OF IRON LOSSES.

(1) *By Subtracting the Friction and Copper Losses from the Total No-load Losses.*—The simplest method of determining the total iron losses is to determine the friction losses by any one of methods 2, 3, or 4 previously given, and to subtract these losses, together with the calculated copper losses, from the total no-load watts required to run the motor light. If either of methods 3 or 4 (Blanc or Benischke) is used, the true friction losses should be obtained by retardation curves as described on page 469, which incidentally gives the rotor losses as a separate item.

If the method 2 (by voltage variation) is employed, the single series of readings enables both friction and iron losses to be determined. Against the simplicity of this method must be set the unreliability of the results already discussed.

(2) *Motor Driven by an Auxiliary Machine.*—By coupling the induction motor to a direct-current machine, so that it may be driven with open rotor circuit, a very complete separation of the no-load iron losses may be obtained. A very full description of the method of carrying out such a test is given by J. Bache-Wiig in the *Elektrotechnische Zeitschrift* for 1906, p. 106.

When running below synchronism with the rotor circuit open, the iron losses in the rotor will increase with decrease of speed. Consequently, by gradually increasing the speed of the rotor up to synchronism by means of the continuous-current motor, the watts supplied to the stator of the induction motor will be found to diminish. At synchronism the only losses in the rotor will be those due to magnetic pulsation in the teeth. At this point also the direction of the torque due to rotor hysteresis will be reversed. After passing the synchronous speed, this effect no longer tends to drive the rotor, requiring power to be taken for this purpose from the stator. The rotor hysteresis is, on the contrary, supplied from the direct-current machine, and power is supplied to the mains owing to this cause. By making observations of the power supplied to the stator of the induction motor, and of the power spent in driving the continuous-current machine, it thus becomes

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possible to measure separately the stator iron loss, rotor hysteresis loss, the pulsation losses, and friction. The last-named is obtained by driving the direct-current motor, first coupled to and then uncoupled from the unexcited induction motor. The experiment requires considerable care, but it is not difficult to carry out if the ratio of alternating to continuous voltage supply can be kept absolutely constant. If the voltages have any relative variation a continual change in the watts taken by the alternating current and direct current machines occurs.

The curves shown in Fig. 13 will be understood from the particulars already given. The lowest curve is the A.C. wattmeter reading (corrected for C^2R), the other curves all being D.C. watts supplied to the driving motor.

It will be seen that the true friction is 136 watts, a value agreeing

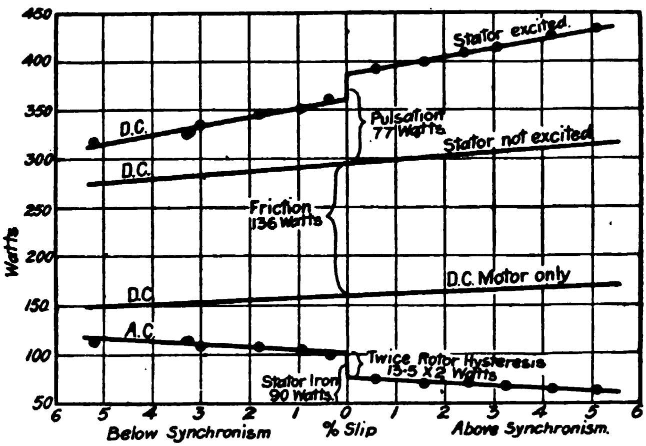

FIG. 13.—Separation of No-load Iron Losses.

closely with that in Fig. 10, but considerably less than is given by the Benischke test, Fig. 11.

The total friction and iron losses are 316·5 watts.

(3) *Method of Angermann.*—Mr. W. Angermann* has proposed an elaborate method for separating the iron losses, which he considers has the advantage over that previously described, in ease of execution—a view which hardly seems to be justified.

Angermann starts by dividing the total iron losses into three groups, each group consisting of those losses which depend upon one factor which can be varied independently of the others. These groups are :—

(*a*) Stator iron losses (exclusive of pulsation losses) which depend on the frequency of supply.

* *Elektrotechnische Zeitschrift*, vol. 26, p. 295, 1905.

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(*b*) Rotor iron losses (exclusive of pulsation losses) which depend on the slip.

(*c*) Pulsation losses in the teeth of stator and rotor which depend on the speed of the rotor.

By varying the frequency of the voltage applied to the stator, with the rotor circuit open, while maintaining the magnetic induction constant, a curve of watts (*a*) and (*b*) is obtained from the readings of a wattmeter in the stator circuit, and is plotted on a base of stator frequency which is also rotor slip.

A second test is made with the rotor circuit closed and motor running light. In this case, again, the frequency is varied and the induction kept constant. A curve of watts (*a*) and (*c*) is obtained from the readings, the rotor slip being assumed too small to produce iron losses.

Finally, a third set of readings is taken with the stator short-circuited and the rotor supplied with alternating currents of the same voltage as those which would be generated at each speed by the voltages applied to the stator in the former two tests. For this purpose the ratio of transformation must have previously been taken. This test gives the losses (*b*) and (*c*).

By adding the ordinates of any two of the curves thus obtained, after correction for C^2R loss, and subtracting the ordinates of the third, each set of losses may be obtained separately. The friction losses must have been previously separated and the values of stator and rotor resistances accurately measured, since the copper losses will bear a large ratio to the total losses in the experiment.

The wide range of speeds, corresponding to values of the slip, which would be never reached in actual working for which the various tests have to be carried out, the variations in the nature of the supply voltage and the number of incidental measurements, *e.g.*, transformation ratio, resistances, etc., combine to make the method anything but convenient in practice. Where complete separation of the losses is required and careful measurement is possible, method (2) seems to be far preferable.

(4) *Retardation Methods.*—The experiments of Bragstad and La Cour, in which the rotor is excited with direct current in order to provide the rotating field, have already been referred to. The iron losses were determined in two alternative methods. In one case the rotor was short-circuited and the motor run light from an alternator having constant excitation, but whose speed was varied from a maximum value downwards. A curve of watts on a base of speed was then obtained, in the same manner as in the second measurement mentioned above in Angermann's test.

The second method of obtaining the iron loss curves was by allowing the motor to retard with direct current supplied to the rotor of sufficient strength to produce the same alternating voltage at the stator terminals, as employed in the first test. The rotating field and

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iron losses were thus due to the rotation of a constant field formed by direct currents in the rotor. From the retardation curves the iron and friction losses at any speed were calculated in the usual way, the predetermined constant being used.

By plotting the iron-loss curves (obtained from the total watts by subtraction of C^2R and friction losses) on a base of frequency, the losses proportional to frequency are separated and classed as "hysteresis"; while the losses varying with a higher power of the speed form the remainder, classified as "eddy-current" losses. An obvious criticism to be made of the experiments is the comparatively small practical value of the results, owing to the fact that the location, and consequently the cause, of the "hysteresis" and "eddy-current" components of the total loss are not determined.

In exciting the rotor with direct current to produce the rotating field, an assumption of practical uniformity of this field is made. Although this may perhaps be justified in the case of normal motors,* it may not be admissible in the case of motors on which it is necessary to make such special tests, and which would possibly not be chosen for such treatment if they were of the usual design.

Quite recently, indeed, after this paper was practically written, Mr. T. F. Wall† has published the results of a number of experiments carried out by the retardation method for separating the iron losses in induction motors. He does not give the method of observation employed in deriving his retardation curves, but the results appear to be very accurately obtained.

His principal object was the separation of the pulsation losses. This he carried out by allowing the motor to retard from full speed with excited stator and open rotor, first in the ordinary manner and then with the direction of the rotating field reversed, so that it rotated in the opposite direction to that of the rotor. The pulsation losses are unchanged by change of direction of the rotating field, while the remaining iron losses are affected by this reversal. By subtraction he was thus able to isolate the pulsation losses.

In conclusion, I have to express my indebtedness to the Committee of the Municipal School of Technology, Manchester, to the Principal, Mr. J. H. Reynolds, and to Professor Schwartz, for the facilities for carrying out the tests described in this paper.

For assistance in carrying out the experiments I am especially indebted to Mr. H. Gill and Mr. R. K. Keer, B.Sc.Tech. Both Mr. Gill and Mr. Keer, were most unwearying in assisting in the tests described (and many others preliminary to them), while their ability rendered the help thus given of the greatest value.

I wish also to thank Mr. A. L. Wood and Mr. J. Davies for assistance in some of the measurements.

I cannot close without a word of thanks to my friend Mr. William Cramp for his sympathy and advice on many points connected with

* See Hellmund, *Electrical Review*, N.Y., vol. 49, p. 450, 1906.
† *Electrician*, vol. 58, p. 752, 1907.

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the preparation of this paper, and for his kindness in reading through the manuscript.

Discussion.

Mr. W. Cramp: On reading the paper I was struck by the graphical method involving a retardation curve, mentioned on page 441. It seems to me that the graphical method is capable of a good deal of expansion, and I therefore suggest the possibility of taking a retardation and an acceleration curve for a particular case, and then by drawing in all the sub-normals a complete curve of losses and even of the efficiency for the machine could be plotted. Mr. Cramp.

With regard to the curves in Fig. 2, the author says there are three curves given, the first for 3·9 amperes excitation, the second for 1·9 amperes, and the bottom for zero excitation. Now, there appear to be two bottom curves, and it is rather difficult to decide which one to take.

In Fig. 3 calculated loss curves are given for this same machine, the top curve 3·9 amperes excitation, the second curve 1·9 amperes, and the third curve friction only. Now, if we extend (as I have done) the first curve up to full speed, it will be found that the motor has, with what I suppose is normal excitation and normal speed (3·9 amperes 900 r.p.m.) a loss of 1,500 watts, or some 15 per cent. It seems to me that this is an extraordinarily bad machine, and the result, I think, requires some explanation. Possibly this figure has something to do with the fact that Mr. Oschwald has not continued the curve to the bitter end.

Referring to pages 447 and 448, the author has developed a very interesting formula, which I should like to take in conjunction with some results on page 454, derived from this formula. I should like to lay special stress upon the extraordinary simplicity and usefulness of the equation numbered 6. The fact that losses or efficiency can be given in such an easy form, involving only a few careful time readings, and dispensing altogether with the calculation of moment of inertia, is an idea which is new to me, and ought to be invaluable in the test-room. The development is most ingenious, and very clearly expressed, I think. Indeed, the example given shows the author how easy it is of application. I regret very much that he has not said anything as to its application to series wound motors, where, I think, a field of usefulness exists, if anything, greater than that which includes the shunt motor.

Referring to Fig. 4, which shows the retardation and acceleration curves as practically straight lines, I should like to ask if it is not possible if these lines run so very straight just to take four readings for any motor coupled to a flywheel, and draw in straight lines corresponding to these four readings. Should I be right in assuming that the 20-ampere retardation curve could be taken as a straight line down to the bottom, or very near the bottom? If so, then not only is the taking of the readings very much simplified, but also the graphical

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Mr. Cramp. method which I have just suggested would become extremely simple, as all the sub-normals for one particular curve would be parallel. Can Mr. Smith say what inaccuracies would be introduced by such approximations?

On page 452 the author states that by earlier methods the value of the losses could not be arrived at within about 1 per cent., while his own later values are within two or three per 1,000. This is a percentage accuracy attained in no paper that I have read or heard of on the testing of motors, and I think for this reason alone this paper is extremely valuable.

On page 453 the vexed question of the change of losses from no load to full load is brought in. Over and over again different writers have stated that at full load the increase in the losses is very great, so much so in some cases as to render all deductions from no-load tests useless. The author has come to the conclusion that for the particular motor mentioned on page 453, the difference between no load and full load losses (excluding C^2R) is almost entirely due to brush resistance. This is a most important result. I should like to know if Mr. Smith has had any experience with other motors which would enable him to say once, and for all, that there is only about one-fifth of the change in losses due to stray power other than brush resistance.

With regard to the efficiency test by the use of a separate flywheel, I think the author has shown that for motors up to, say, 50 H.P. it is a very accurate method, and I congratulate him upon his simplified use of the flywheel as a test-room appliance, which he has passed over with so much modesty. In Fig. 6 he has some difficulty in accounting for the losses which occurred between retardation and acceleration. Some of these losses may possibly be due to windage. It does not seem to be realised that the windage losses in a motor may be an extremely big thing. Is it then fair to consider friction losses as due to friction alone, when the windage on a flywheel such as a 9-ft. disc amounts to about 10 H.P. at 500 r.p.m.? And would not this loss be different when accelerating to what it is when retarding?

The author has styled the latter part of his paper "Alternating Current Induction Motors," and I think he ought to have said Polyphase Alternating-Current Induction Motors, because the losses and the methods there given, and particularly the actual formulæ suggested, do not apply to single-phase motors. The iron losses, for instance, are always found greater in single-phase induction motors than in polyphase induction motors; and referring to page 462, I should like to point out that the hysteresis calculation in particular at synchronism is not, I think, true for the single-phase induction motor. Indeed, I do not think that at synchronism the hysteresis loss of the single-phase motor changes sign.

Mr. Frith. Mr. JULIUS FRITH: I am surprised the author has not mentioned a method of separating the losses in a direct-current machine, namely, by taking power curves to run the motor at varying speeds at two

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inductions, say at full and at half induction. Both the current and the voltage curves should be straight lines. The slope of the two-current curves being eddy-current losses the slope of the half-field curve is half that of the full-field current curve, the portion between the base-line and the left-hand end of the current curves gives the friction and hysteresis losses, which can be separated out very easily. I have used this method myself, and in the majority of cases it works out very well. I should like to say a few words abcut the method of retardation and acceleration. I have used the retardation method of separating losses at no load, but it has been my lot to deal with rather heavier machines, that kept running by themselves for a minute or two, and render the flywheel unnecessary, having sufficient inertia in their own armatures. For the full-load curves I do not think the author has laid sufficient stress on the question of brushes; I gather that he uses the same brush lead for the retardation and acceleration curves, that is, when the machine is acting as motor or as generator; the power to drive is seriously affected by the position of the brushes, which require to be very accurately set in order not to get very disturbing results by the currents under the brushes. I take it the machine used was a 100-volt one, in which case the brush loss is likely to have been very considerable. I think the whole question of brush position has been passed over rather too rapidly. Mr. Frith.

I object to the author's use of the term "armature drop." Suppose a machine is run as a generator, and the armature circuit is suddenly opened, there will be a rise in volts, and I think it is a misnomer to call that "armature drop," or "voltage rise"; a large proportion of this rise is due to the liberating of the ampere-turns on the field, which were formerly used for armature reaction; I think this point is obscured in the paper.

Coming to the alternating section, several methods are mentioned of making a rotating field by sending direct current into the slip rings of an induction motor; this, of course, is quite the right way of making a revolving field, but such field might differ from the revolving field caused by the stator currents in having quite a different wave-form and so, whilst giving the same root-mean-square induction, the maximum induction, on which depend the losses, might not be the same at all.

Dr. W. G. RHODES: The paper is eminently useful to designers of electrical machinery. Purchasers do not care at all where the losses occur, or how they occur, so that they are not theirs. They want nett efficiency. I think the question of allocating the losses depends upon what the machinery is required for, whether it is required to run on light load long, or whether it is entirely required to run on full load. If on full load, then the question of design is entirely different to what it would be if required to be always running, and only occasionally put on. In this respect the paper is exceedingly useful to the designer, in fixing these losses, and adjusting them in such a way as to make the machine as efficient as possible for the work it has to do. Dr. Rhodes.

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Dr. Morris. Dr. D. K. MORRIS; (*communicated*): It is now several months since I was at the University of Birmingham, but last autumn I was engaged very hotly in the pursuit of "stray losses" by means of the Hopkinson method. I notice the author says that the difference between the electrical conditions of the two machines which occurs in this method is only troublesome below 10–15 k.w. (see page 456). My own experience is that even with 30 to 40 k.w. it is by no means easy to eliminate troubles due to this cause. The finding of "stray losses" as they vary with load is a hard test on the method, even when troubles due to the coupling or belt are eliminated.

I have endeavoured to get rid of the trouble arising through inequality by a method similar to that given in the transformer paper by Mr. Lister and myself a year ago. This method, which we described in our paper as a modified Sumpner-Hopkinson test, consists, when applied to direct-current machines, in a combination of the series Hopkinson and parallel Hopkinson tests; the pressure of one armature being boosted up, and that of the other being boosted down, while the shunt supply is brought, as it were, to the middle point of the booster. This can be obtained, when special apparatus is not available, by means of a divided carbon rheostat.

This test was fairly successful, and although too complicated to be of much practical use, it has yet the advantage that the *current* in both armatures is more nearly the same, as in the series Hopkinson test; while at the same time the *field strengths* are also more nearly the same.

Mr. Murdoch. Mr. W. H. F. MURDOCH: Referring to the curves of losses in Fig. 6, it hardly seems to me that the author's explanation of the difference between the shapes of the loss curves when accelerating and retarding, can be the correct one. In the first place, the shape of the no-load curves is different from that of those at full load, the latter being practically straight lines when retarding. Further, the difference between acceleration and retardation curves appears to increase with the load. From both of these considerations, I should be inclined to attribute the difference to some function of the load, that is, to an electrical or magnetic effect, rather than to frictional losses which, it is to be anticipated, would be independent of load.

Mr. Oschwald. Mr. U. A. OSCHWALD: Having seen the reports of the discussion, and noticed that reference was made to the curves which I had taken on the Ondograph, I should like to make one or two comments.

For the curve obtained with an excitation of 3·9 amps. (see Fig. 2), the motor was run at about 100 volts, the speed and voltage at this excitation being about 350 revs. per min. At the full speed of 900 revs. per min. with this excitation the terminal volts would have been, say, $\frac{100 \times 900}{350} = 260$ volts. If the driving losses were 1,500 watts, as estimated by Mr. Cramp at this speed, the percentage loss would be $\frac{1{,}500 \times 100}{26{,}000} = 5{\cdot}8$ per cent., instead of 15 per cent. as Mr. Cramp has calculated.

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Mr. Oschwald.

The idea in carrying out the test was not so much the determination of the losses in this particular machine, as to test the suitability of the Ondograph for such purposes.

The test might have been made at a higher voltage and at full speed without difficulty, but it was not considered necessary to do this, and it would have necessitated some troublesome rearrangement of apparatus.

On page 474 the author states that the ratio of alternating-current to direct-current voltage should be kept absolutely constant. This point I cannot quite understand. I take it that to reduce the speed of the rotor to a value below synchronism it will be necessary to reduce the terminal voltage of the direct-current motor by means of a rheostat. Will the alternating-current supply to the stator have to be correspondingly reduced?

Mr. Smith.

Mr. C. F. SMITH (*in reply*): Mr. Cramp has made a very interesting suggestion in connection with the diagram shown in Fig. 1, namely, that the curves of losses may be directly plotted from the combined acceleration and retardation curves without the trouble of using the constant. This certainly may be done. The reason why I have not in my own work adopted the graphical value of the slope of the curve, and why I have not used the sub-normal as I have mentioned on page 441 might be done, is that I found I could get more accurate values for the slope of the curve by actually using the curve itself, rather than continuing the tangents as long lines to a considerable distance, where the error due to any want of parallelism and so on would be considerably magnified. I doubt, in consequence, whether a graphical construction carried out would have quite the same accuracy as one in which the points are carefully pricked off from the actual curve itself by needle-point dividers, but I can see that there may be ways in which it might prove of use.

In Fig. 2 Mr. Cramp says there are two bottom curves; really there is only one, although it looks like two. The two straight lines are the continuation of a single curve. As regards the watts plotted on the next curve, I have noticed the apparently excessive value of the iron losses shown on the top curve alluded to by Mr. Cramp, but have not gone so far as to calculate the value which these losses would have at full speed. The actual experiment was not really quite as satisfactory as it should have been, on account of the fact that the range of the voltmeter was not sufficient to take in the full range of the voltage, that is, the voltage of the machine when fully excited at full speed was considerably above the range of the voltage of the Ondograph as that was used, and it is probable that the top curve is not really a very reliable one. If the voltmeter had been adjusted beforehand, so that its range corresponded to the range of readings required, the method should have been quite accurate. Mr. Oschwald has kindly supplied the curves, rather to illustrate a method than to give actual values, and, as will be seen from Mr. Oschwald's communication, the losses hardly work out to the values given by Mr. Cramp. Referring to Fig. 4,

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Mr. Smith. Mr. Cramp says the lines look so like straight lines that he suggests taking only two points on them in order to obtain the complete line. With regard to that, I should say that the lines, when fully plotted out on a large scale, are not sufficiently straight to make it possible to determine them completely by taking readings far apart. Mr. Cramp's suggestion might be adopted in the form suggested, namely, that instead of observing speeds at equal intervals of time, it might be simpler to read the time interval between the passage of the motor through different speeds. For instance, if the time was noted when the readings were 1,000, and then a stop-watch was set and the time taken for the speed to fall to 800, the time intervals might be quite long enough to read accurately, and the curves taken between the points might still be sufficiently straight to make it unnecessary to take more than one such reading at, or near, the working speed of the motor.

Regarding the losses shown in Fig. 6, I do not think that air friction or windage as suggested by Mr. Cramp could possibly account for the difference in the shape of these two curves, because at a given speed the windage loss must be exactly the same whether the machine is acting as a generator or as a motor. I do not see how windage can possibly make any difference in the shape of the curves. In regard to the losses to be expected in other machines, as I have mentioned in the paper at the end of the first section, my experiments were only carried out on one machine. The particular flywheel I had available was mounted on bearings which practically made it impossible for any other motors to be put on to it, so that I have not had the opportunity of making comparative tests.

The method is equally applicable to series motors, and I hope shortly to be able to show further curves of losses obtained on a series machine. Mr. Cramp is perfectly correct in pointing out that the second part of the paper has to be taken as applying only to *polyphase* induction motors.

With regard to Mr. Frith's remarks, his description of the method he has used for separating the losses in direct-current motors is exceedingly interesting, and I am very glad to learn how simply it can be done, and that the results in practice are so satisfactory. The method appears to be a special application of the principles mentioned on page 438 of the paper.

With regard to the position of brushes, I think I have used the term "drop" in a sense which Mr. Frith has misunderstood. The drop I meant was the difference between the terminal volts and the generated volts, and I quite admit that the drop used in that sense might often be more largely due to armature reaction than to actual resistance. The importance of the position of the brushes is shown by the curves in Fig. 9.

The objection to the continuous-current excitation of the rotor in order to produce a rotating field has been pointed out on page 476.

I thank Dr. Rhodes for his remarks, but think that they need no

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special reply. The observations kindly contributed by Dr. Morris, Mr. Murdoch, and Mr. Oschwald all have their special points of interest. With reference to the Hopkinson test, I can well believe that, when employed for determining stray losses, and not for simple efficiency determinations, errors due to unequal loading, etc., might affect the results even for quite large machines. Mr. Smith.

In reply to Mr. Oschwald's question, it is only *irregular* variations in the ratio of continuous-currrent to alternating-current voltage which must be avoided. The actual ratio of the voltages is varied in the experiment alluded to, in order to vary the slip of the machine.

In conclusion, I can only express my very great thanks to the members for so patiently listening to a hurried summary of the paper, and I wish particularly to thank those gentlemen who have so kindly contributed interesting remarks and criticisms.

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DUBLIN LOCAL SECTION.

TECHNICAL TRAINING OF ELECTRICAL ARTISANS.

By C. P. COOTE CUMMINS, Associate Member.

(*Paper read April* 11, 1907.)

The training of electrical artisans, as distinguished from the training of electrical engineers, is of such importance to the electrical profession that it is a matter for surprise that it has not received more attention from employers than has been the case in the past. So little attention has it received that it is doubtful whether many of us, if called upon to do so, could give a clear definition of the sort of individual we refer to when we speak of an "electrical artisan." This is, perhaps, not surprising when we remember that the question as to what does or does not entitle any individual to call himself an electrical engineer is a matter of considerable difficulty.

In this paper I intend to deal with the training of electrical artisans only, and, to avoid misapprehension, it is well to state that when I use the term I include all those persons who have served a certain apprenticeship, and have subsequently obtained fairly continuous employment at industrial occupations connected with the practical applications of electricity. Wiremen, telegraph and telephone linesmen, electric bell fitters, armature and bobbin winders, electrical machinery attendants, electrical instrument makers, and makers of electrical fittings and accessories are, therefore, all included, but as probably 99 per cent. of the electrical artisans to be found in Ireland at present may be classified as wiremen, and as I have been requested by the Honorary Secretary to the Dublin Local Section to make some suggestions in this paper with regard to the possibilities of improving the existing methods by which such men are trained, my remarks refer almost exclusively to this class of electrical artisan.

EMPLOYERS' REQUIREMENTS.

From the point of view of the employer, the following are probably the requirements of a really competent wireman: (1) He must be steady and reliable. (2) He must be a good timekeeper and a hard worker. (3) He must be sufficiently intelligent to receive verbal and

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frequently hurried instructions as to carrying out a job, and then be able to carry it out economically and satisfactorily. (4) He must be capable of running wires and fixing in position the suitable casing or conduit, also the necessary fittings, such as fuses, switches, etc., in their proper places. (5) He must have a general knowledge of the different systems of house wiring; of the differences in supply systems, and the changes in fittings and apparatus necessitated by these differences; of testing insulation; of the mechanism of arc lamps, motor-starting switches, other electrical apparatus; of gas and steam engines; of the current-carrying capacity and insulating properties of wires and cables; and of complicated wiring work, such as is required for switchboards, etc. (6) He must be able to overhaul a customer's premises, make good minor effects, and make a short, clear report of the work done and of any further work required.

The number of men who approach this standard is, I fear, very small, but, nevertheless, it will scarcely be contended that a competent man does not need all the above qualifications, and if he does not possess most of them, he would be unlikely to obtain employment as foreman over an important job. I do not, of course, maintain that all these qualifications are always essential; it is not to be expected or desired that all the men should possess foremen's qualifications, and when it is not necessary to entrust the men with any responsibility or supervision a far lower standard would be sufficient. Unfortunately, however, a very large portion of the work undertaken by electrical contractors consists of small jobs which are not sufficiently remunerative to warrant the head of the firm devoting a sufficient amount of his time to their proper supervision, and he is consequently forced to rely to a very great extent upon the competency of his workmen; there is, therefore, a pressing need for men who are capable of looking after and appreciating the hundred and one small details, attention to which means so much as regards subsequent freedom from faults and satisfaction to customers.

Existing Methods of Training.

Boys who wish to become wiremen have generally been educated in the primary schools. They usually apply to one or other of the electrical contractors, who frequently accept them without premium, and put them to work at a small weekly wage as boy assistants to wiremen. The boys' chances of learning depend upon the proficiency of the wiremen whom they assist, and upon their powers of observation. After a time they acquire a certain amount of proficiency in running casing and wires, soldering joints, etc., and fixing switches and other fittings in position. They also see dynamos, motors, gas engines, and possibly steam engines installed, and learn something about their management. Generally the boys' wages are increased periodically, the increase in some cases depending upon the amount of proficiency which they show, and at the end of five or six years they may, perhaps, be paid at the rate of 8d. per hour. Having reached this rate they are

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recognised as wiremen, and can be enrolled as members of the trades' union society.

Some contractors endeavour to make the boys attend evening technical classes during this period of training, but few attend with any regularity or show any seriousness in their studies. The work done in the evening classes is usually arranged to meet the requirements of the elementary syllabus in electricity and magnetism of the Board of Education, South Kensington, and of the more advanced programme of the City and Guilds of London Institute; both of these examining bodies award certificates to candidates who pass the examinations satisfactorily. The value of the certificates as evidence of competency is not, however, generally recognised, and it is sometimes contended that the instruction given under these programmes does not increase the boy's usefulness to his employer.

Results obtained by Existing Methods.

The results obtained by the existing methods are, as might be expected, very indifferent. Few of the men who consider themselves wiremen, and who demand and obtain 8d. per hour, possess qualifications equal to those which I have outlined. The steadiness and reliability of the men are not subjects for consideration in a paper of this nature, and eliminating these personal factors, wiremen may be divided, as regards their efficiency, into certain groups. I believe that all the existing men may be classified in one or other of the following:—

Group 1.—Men who can run casing and wires and put up fittings fairly well, if the exact positions are clearly marked out, but who cannot be relied upon to lay out work for themselves.

Group 2.—Men who can receive verbal instructions as to a small house-wiring job, and who can be relied upon to run the casing and wires in the most economical way, and to put up the fittings in the most convenient places.

Group 3.—Men who are competent under group 2, and who know how to connect up and adjust electrical apparatus, such as arc lamps, motors, etc.

Group 4.—Men who are competent under groups 2 and 3 and whose knowledge of wiring, testing, and electrical apparatus enables them satisfactorily to carry out, under supervision, switchboard or complicated wiring work and the installation of generating plant.

Group 5.—Men whose knowledge and experience are sufficient to enable them to act as foremen over a job consisting of a complete installation, including house wiring and supply of generating plant.

Very few of the existing men can be included in groups 4 and 5, and the majority are not even eligible for group 3. It is very doubtful whether the labour of men classified below group 3 is worth 8d. per hour, and the fact of there being large numbers who can only be classified in group 1, and who can, nevertheless, obtain this rate of wages, is evidence of serious defects in the method by which electrical

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artisans are produced. The present methods of training must, therefore, be considered defective, inasmuch as they produce a considerable number of men who cannot be considered competent, large numbers who can only be considered partially competent, and a very few who are really competent, and also because, as a natural consequence of this defect, the really competent men consider themselves in such a strong position, by virtue of their small numbers, that their demands upon employers, and their general independence, very materially reduce their usefulness.

Opportunities which Electrical Artisans have for Qualifying Themselves.

It is quite obvious that intelligent work—*i.e.*, work which bears evidence of a knowledge of the fundamental scientific principles underlying it—cannot be expected from workmen who have had no opportunity of studying those principles. This probably applies with the greatest force to electrical work, because in dealing with electrical phenomena the uneducated workman is handicapped to a far greater extent than his fellows in other trades, inasmuch as he does not possess what Professor Ayrton calls "an electrical sense." The mechanical artisan who could not fully appreciate the necessity for not putting an excessive strain upon a small screw thread, even though he had never studied mechanics, would be rightly considered lacking in intelligence. It would be most unfair, however, to pass similar judgment upon the electrical artisan who, without any previous study of electrical science, was unable to appreciate the necessity for not subjecting the insulation of an electric circuit to an excessive electric pressure. An electrical sense can be acquired, and its cultivation is of the first importance to an electrical artisan if he wishes to be able to work intelligently. Unfortunately, however, the methods of training which I have outlined show a lamentable failure to recognise this vital point. The existing workmen from whom boys have to glean their knowledge, in ninety-nine cases out of one hundred, possess no electrical sense, and in the remaining case have no time to spend in imparting it. The boy's opportunities for acquiring it while at work are practically nil, and unless after a long day's work he spends his evenings and spare hours reading electrical text-books, which are generally out of his depth and frequently inaccurate, or at technical classes, he will probably never acquire it at all. This being so, it is surely not surprising that so few competent electrical artisans are to be found.

Defects in Present Methods of Training.

There are, undoubtedly, many good points to be found in the present methods of training, but it can scarcely be denied that the results obtained are not all they ought to be, and, as I have already indicated, the reason for this is, in my opinion, the absence of any special provision by which the boys from whom the ranks of electrical artisans

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are recruited shall be trained to form mental pictures of what is taking place in electric circuits. It is not sufficient merely to exhibit the different electrical phenomena; very few boys inherently possess the mental power necessary for a clear understanding of them. The majority of us were not born with an electrical sense; consequently, in order that we may work intelligently, we must train ourselves in mentally reducing electrical phenomena to their corresponding physical phenomena. When we have acquired this power we possess what I have referred to as an electrical sense, and unless electrical artisans possess it, it is very doubtful whether they can be really efficient. I do not contend that it cannot be acquired outside the classroom; on the contrary, the many first-class men who exist and have never attended technical classes clearly disprove this, nor do I wish to assert that it can always be acquired in technical classes. I have seen boys who have a fatal facility for passing examination tests, but who have never acquired an electrical sense, but I believe that the large majority cannot acquire it by simply handling electrical apparatus and working at the practical applications of electricity; and I also believe that 99 per cent. of those who apparently do acquire it in this way will be found to have started with a sound elementary education, which they never allowed to slip away from them, that they possess an exceptional amount of grit and determination to succeed, and that had they been judiciously assisted they would have reached their high standard of efficiency with an expenditure of far less mental energy. My experience has convinced me that it is far easier to impart an electrical sense to electrical apprentices than to those whose daily occupations do not involve the constant handling of electrical apparatus (provided the apprentices possess a sound elementary knowledge of reading and writing the English language, and of arithmetic), and I believe that a system of training which did not include a period of apprenticeship would be almost useless; but, unfortunately, in our present system :—

1. Boys taken as apprentices often possess a very small amount of general education.

2. More often than not several years elapse before they realise the importance of studying, and when they join evening classes the small amount of general education which they once possessed has almost disappeared.

3. The importance of boys continuing their education after leaving school by immediately attending evening classes is not sufficiently emphasised, and the advantages of having spent five or six years at school are not made clear to them; consequently they are apt to undervalue their education and to make no effort to retain it.

4. The facilities afforded to apprentices for continuing their studies until they have reached a standard of knowledge sufficient to be of practical use to them are, in the majority of cases, quite inadequate.

5. No generally recognised standard of qualification exists for electrical artisans, to the attainment of which boys can from the outset be *encouraged* to direct their energies.

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These are all very serious defects, and of such a nature that unless employers generally recognise them and take concerted action they cannot be removed.

Reasons why Employers should Interest Themselves.

The advantage to employers of a larger number of competent men being available is, I presume, sufficiently recognised to need no further reference; there are, however, some special reasons why employers should take steps to remedy the defects I have indicated, which may not have heretofore been fully recognised. A moral, if not a legal, obligation rests upon employers, especially if they accept a premium, to do everything in reason to assist apprentices in becoming fully qualified; and as the importance of education is now so fully recognised that it has been made compulsory in its elementary stages, any system of training which does not make provision for continuing the education of the apprentices to such a point as will make it of practical use to them cannot be held to be reasonable. As such a system must result in the waste of some portion of the money expended in the primary schools, which money has been expended with the object of developing a valuable national asset, the continuance of the system is illogical.

By permitting the present system of training to continue, employers are forfeiting the benefits which should accrue to them as a result of the national expenditure upon education; if employers would recognise that they have a right to participate in the advantages to be derived from these funds, and by co-operating with educational authorities insist upon the education being arranged with due regard to their requirements, much might be done to improve the conditions of labour which they are frequently so ready to complain of.

Proposed System of Training.

Having outlined the principal defects in our existing system of training, it will be fairly obvious that, in my opinion, the following points should receive special consideration in any revised scheme of training.

Boys should not be taken as apprentices, either with or without fee, unless they possess a sufficient general education.—In cases where employers are in doubt as to whether applicants for apprenticeship possess this knowledge, the local technical school authorities will probably gladly assist the employer by examining the candidate and making a report, without any cost to either the employer or the candidate. The necessary amount of education should be very carefully considered and a minimum standard adopted by the employers, who could count upon receiving all the assistance and the information they required, to enable them to arrive at a decision, from the education authorities. Without going into details as to the minimum standard of education required, I am strongly of opinion that it should not be very low. Few boys under the age of sixteen are physically fit for apprenticeship, and as they usually leave the primary schools at fourteen, they can spend

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two years at one or other of the day trade preparatory schools which are now being established in connection with many technical institutes. It appears to me that the very great value to them of trade preparatory schools has not yet been fully recognised by employers, although I should like to take this opportunity of tendering my sincere thanks to the many employers in Dublin who so kindly interested themselves in the project when my committee established one of these schools. In my opinion, there can be no comparison as regards probable future efficiency between two boys, one of whom has spent some years, after leaving the primary schools, in a school where the whole instruction has been arranged specially with the object of increasing his usefulness to his employer—*i.e.*, in teaching him how to make use of his education as a useful tool in connection with his life's work—whilst the other has either done nothing since leaving the primary school or has earned a few shillings a week as a shop messenger or in some similar capacity, with the result that the greater part of his primary school education has been forgotten. One would imagine that the value to employers of securing such apprentices would be so great that, before taking others, they would at least make inquiries as to whether any such boys were available, or perhaps go as far as offering one or two vacancies per year for competition amongst the boys at such a school. Offers of this nature would cost the employers practically nothing, and they would be of invaluable assistance to those who are endeavouring to establish day trade preparatory schools, in the development of which one of the most serious obstacles is the difficulty of inducing the parents of intelligent boys to forego the few shillings a week which can be earned by the boy between the ages of fourteen and sixteen.

During their apprenticeship, and as a necessary condition of it, boys should be required to attend certain specified classes in a technical school. There should be a properly arranged course of instruction for each year of apprenticeship, and attendance at it should be rigidly enforced. Also on the days or hours upon which the boys are required to attend technical classes, they should not be expected to remain at work for the same number of hours as on other days.—It is probably not generally known that the Department of Agriculture and Technical Instruction for Ireland have quite recently revised the scheme for the administration and distribution of grants to evening technical schools, and in their new programme special provision and very liberal grants are offered to schools which develop a systematised course of training, extending over several years. They have decided to issue certificates to students who have followed an approved course, but the subjects of the course and the nature of the instruction may be varied to suit the requirements of different localities or of different trades, and there are, therefore, at the present time, exceptional opportunities for developing a satisfactory system of training. The present system, by which boys are expected to attend evening classes after they have done a long day's work, which generally necessitates early rising, is fundamentally wrong, because it demands a prolonged mental effort when the boy is physically

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tired. It is not reasonable to suppose that any but the most exceptional boys can respond to such a demand, and by making it we really defeat the object we have in view, because it is a well-known fact that the best results are always obtained in class work when the boys are physically fresh. In addition, there is the very serious objection that burning the candle at both ends must sooner or later injure the boys' health.

The course of instruction to be followed during each year of apprenticeship should receive very serious consideration from employers, and should be drawn up by them.—In this connection they could also rely upon every possible assistance from educationalists and education authorities, but they should be careful not to be guided to too great an extent by the opinions of others. Few educationalists are capable of arranging and conducting a course of instruction which will be acceptable to the majority of employers, because they are generally too much in contact with the educational side of the question, and it is very difficult for them fully to appreciate that from the point of view of the employer, who, in spite of himself, is forced to judge all proposals in connection with the management of his business by their profit-earning capacity, The educational aspect is of minor consideration, and the really important point is the capability of the training to provide him with efficient workmen. I do not think that educationalists sufficiently realise the fact that, in endeavouring to interest employers in the education of their apprentices, they must treat the matter on strictly commercial lines. Employers do not, and should not, conduct their business on a philanthropic basis, and in the competition and stress of modern business life an employer cannot afford to introduce reforms unless he is convinced that they will be to his advantage. The admitted need for efficiently trained men is the educationalist's opportunity, and he must do everything in his power to satisfy this demand, but he cannot hope to succeed unless he can associate the employer with him. I have never met an employer of skilled labour who refused to admit that properly arranged classes for his apprentices might be an advantage to him, but I have met many who have denied the existence of such classes. This is evidence that many employers are doubtful as to the value to them of technical training, and the industrial future of the country must, in my opinion, be seriously injured if this doubt is not removed. My sympathies are, to a great extent, with the employer. I well know how frequently the boy who is represented to him as having done splendidly at school, and having a natural aptitude for practical work, turns out to be an utterly useless apprentice, and I can well understand the man who has accepted such an apprentice registering a vow never to repeat the mistake. To my mind, technical education of apprentices which at the close of the period of training has failed to provide the boy with a tool which he has always ready to his hand, and upon which he has learnt to rely with greater certainty than upon any other tool which he has learned to use, is almost, if not quite,

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useless, and is certainly not worth the money expended upon it. I admit that the development of a proper system of training is exceedingly difficult, but it is because of the existing systems having to a great extent failed in the above respect that so many employers doubt the value of education. The only possible way to remove this doubt is by inviting the employers to share the responsibility. If they will state their needs and their ideas as to what ought to be taught, I believe that their suggestions will be most gratefully received and acted upon to the very fullest extent by all education authorities, from Government departments to local technical instruction committees; but if they will not do so, and if they fail actively to co-operate with education authorities in devising and putting into operation a suitable scheme of training, it will be most inconsistent of them to criticise destructively the efforts of others whom they severely handicap owing to their refusal. Shortly, I believe it is absurd to make appeals based on anything but the simple facts that employers require efficiently trained artisans; that educational authorities have been established, partly at the expense of the employers themselves, to assist in providing these workers; that the training cannot be efficient without the active co-operation and assistance of the employers (not necessarily monetary assistance); and that if the employers withhold this, the responsibility for failure rests with them.

In their own interests employers must see to it that a suitable system of training is devised and put into operation; that the fads of individuals are not permitted unduly to hamper the proper working of the system; that the examinations and certificates held and awarded by public examining bodies are arranged to fall in with the requirements of the system; and that the boys themselves are given every possible encouragement and assistance in making themselves proficient.—The matter is too important to be dealt with by individuals. It deeply affects the future of our profession, and as I imagine that the large majority of electrical employers are members of this Institution, I would suggest that an advisory committee on education be formed, similar to those already in existence in regard to other branches of the profession, and that this committee shall carefully consider the matter and prepare a general scheme, leaving the details of organisation and management to the different local sections. By adopting this suggestion, electrical engineers would only follow in the steps of other employers who are interested in the same question. The principal employers of motor-car drivers (the Automobile Club of Great Britain and Ireland) have taken the matter in hand, and have arranged themselves to examine and certificate their drivers; and I am pleased to be able to say that the attitude of this body of employers has been fully recognised by all the educational authorities concerned in the management of the Pembroke technical schools, with the result that full courses of instruction are now arranged in those schools, with the object of preparing men for the club's examinations, the course of training having received the official sanction of the Irish Automobile Club

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and of the Department of Agriculture and Technical Instruction for Ireland.

The following, which I have extracted from a copy of the *Times* issued in February last, is also of interest: "An interesting movement is now in progress among the plumbers to bring about harmonious working, and to render the conditions respecting the admission of apprentices, as far as possible, uniform throughout the country. United action has been rendered possible by the appointment of an advisory committee on plumbing, on which the City and Guilds of London Institute, as the chief examining body, the Worshipful Company of Plumbers, who seek to enforce registration, the National Association of Master Plumbers, representing the employers, and the United Operative Plumbers' Association, which is the principal trades' union of the men, are each represented by three members. This committee is presided over by a delegate appointed by the Board of Education, and after many meetings it has been possible to draw up a syllabus of examination which seems likely to satisfy all parties. Moreover, the master plumbers have agreed that if this syllabus is adopted they will undertake that henceforth all their apprentices shall be bound by indenture to present themselves for this examination, which will thus become the regular means of entering the trade. This will be probably the first trade in the country to enforce an examination test on its apprentices."

In his recent inaugural address our president, Dr. R. T. Glazebrook, referred at considerable length to the question of standardisation, and gave some interesting extracts from Dr. Shadwell's recently published book on "Industrial Efficiency," in which the conditions under which industries are carried on in England, Germany, and the United States—the three leading industrial countries—are compared. As Dr. Glazebrook says, the conclusions are not altogether in our favour, and he gives the following quotation: "England is like a composite photograph in which two likenesses are blurred into one. It shows traces of American enterprise and of German order, but the enterprise is faded and the order muddled. . . . We are a nation at play."

There are two points of special interest in the above remarks. Firstly, in referring to the three leading industrial countries, England is coupled with two other countries whose industrial development, when compared with her own, is of recent growth; and, secondly, of the three countries, the one which has had the longest industrial career is not the one which appears best in the comparison. It is significant that in both the other countries, education has been developed to a point almost unknown in England.

In this paper I have not attempted to draw up a syllabus of the work which should be done in the different technical classes, nor of the manner in which the teaching should be carried on. Many points present themselves to one in this connection, but to deal with them adequately would occupy too much of your time, and as I have already emphasised the point that employers should not rely to too great an

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extent upon the opinions of others in matters of this nature, I do not think this paper is the proper place for introducing my opinions. In conclusion, the ideas I have endeavoured to put before you have been formed as the result of a considerable number of years' experience in teaching and organising classes suitable foi electrical artisans and others in the Dublin district, during which time I have come in close contact with all the difficulties to which I have referred, and have discussed them with many employers. I do not, of course, claim any originality for the suggestions which I have made, or that there are not many better suggestions which have not occurred to me. The training of electrical artisans is a matter which has interested me intensely for many years, and if I have succeeded in awakening your interest to the extent of bringing about a serious discussion as to the advisability of taking some steps to improve the existing methods of training, I shall feel amply repaid.

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GLASGOW LOCAL SECTION.

A NEW LEADING-IN CONDUCTOR FOR ELECTRIC LAMPS.

By C. O. BASTIAN, Member.

(*Paper read May* 14, 1907).

The difficulty of permanently maintaining a vacuum in an electric lamp is not satisfactorily overcome by the use of platinum for the leading-in conductors, as the costliness of this metal tempts the lamp maker to exercise excessive economy in the cross-section and length of the platinum used, and leaky seals may be the result.

The form of seal usually known as the Siemens' seal—although the idea seems to have been originally suggested in one of Mr. James Swinburne's early patents—permits of economy in platinum within certain limits, but these limits are too often strained whenever the price of platinum rises, and the market is consequently flooded with short life and inefficient lamps, to the disgust of the consumer and the discredit of the manufacturer.

In the Siemens' seal the platinum is completely embedded in glass, being merely a bridge between two heavier conductors, usually of copper and nickel. Now the cooling effect of these two heavy conductors, plus the cooling effect of the mass of surrounding glass, permits the use of platinum having a very small cross-sectional area, and theoretically—though not practically—the length of platinum wire may be cut down to a minimum.

Exactly how far it is practicable to reduce either or both of these dimensions has apparently not yet been ascertained by lamp manufacturers, but it is certain that the recent rapid and considerable rise in the price of platinum is calculated to lead many to attempt a reduction below the limits of safety, and the introduction of some cheap and effective substitute for platinum, which would not be subject to wide fluctuations in price, is now more than ever desirable, not only to the lamp manufacturer, but more especially to the lamp user, to whom lamps with an imperfect vacuum mean increased cost of renewal, perhaps 25 per cent. increase in the bill for electricity or poor light due to rapid blackening of the glass bulb.

It would unduly lengthen this paper to describe the many ingenious but unsuccessful attempts to solve this problem that have been made

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since the early history of the incandescent electric lamp, but that all attempts hitherto have been unsuccessful is sufficiently evidenced by the fact that platinum is still used by every manufacturer in this country, although at the time of writing the metal is quoted at £7 10s. per ounce, and last year it touched over £8.

Nickel and steel can be alloyed in such proportions as to have practically the same coefficient of expansion as glass, but leading-in wires of this alloy have not found favour in this country, although it is used in certain cheap foreign-made lamps. The surface of the wire becomes oxydised during the sealing-in process, and the thin layer of oxide is sufficiently porous to allow air gradually to percolate through, so that lamps made with this nickel steel alloy cannot be stocked for any reasonable length of time without deterioration.

In selecting a suitable conductor for this purpose, the coefficient of expansion is by no means the only detail to bear in mind, and one is limited in one's choice by quite a number of essentialities, which may be set out as follows:—

(*a*) The metal must be cheap.
(*b*) The melting point must be higher than that of glass.
(*c*) The quantity of gas occluded must be as small as possible.
(*d*) There must be absolutely no tendency to oxydise when heated in air to the temperature of molten glass.
(*e*) The coefficient of expansion must be as near that of glass as possible.
(*f*) The conductivity must be as high as possible.

The leading-in conductor now to be described has been chosen with due regard to all the above points, and it is the result of experiments extending over several years in the author's laboratory, the final solution of the problem being due to the ingenuity of Mr. George Calvert.

A copper wire of any desired gauge is selected, and of sufficient length to extend from the lamp cap to the filament. Near one end, and along 15 mm. of its length, this wire is rolled flat to a thickness of 0·075 mm., as shown in Fig. 1.

FIG. 1.

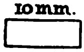

FIG. 2.

Next a 10 mm. length of soft enamel glass tube is slipped over the flattened portion of the conductor, and is melted on to it with a blow-pipe flame.

If this blow-pipe flame is properly applied under suitable conditions, the enamel glass can be melted on to the flat copper without the latter

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oxydising in the slightest degree, and the enamel will then adhere to the clean polished metallic surface just as solder would adhere.

The enamel and copper appear to be actually joined together—amalgamated, as it were, one with the other—and not merely in juxtaposition.

It will be evident that this glass-coated metal can now be heated up to any desired temperature short of the melting point of the copper, without the latter becoming oxydised, because the glass coating will effectually prevent the access of oxygen to the surface of the metal underneath it. There is, therefore, nothing to prevent conductors thus prepared being sealed into a lamp stem, as shown in Figs. 3 and 4,

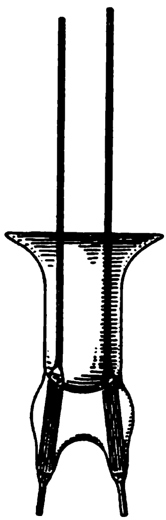

FIG. 3.

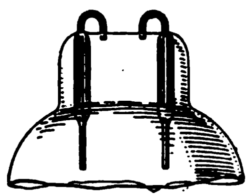

FIG. 4.

and such seals have proved most perfect in practice, and have successfully withstood the very severe tests to which they have been subjected during the last eight months.

Out of the first batch of carbon filament lamps made with these leading-in wires—Sineplat wires, as they are termed by the makers—30 were selected for a "life" test. They were arranged in two separate groups of 15 each, and connected with a time switch, so that each group was alternately lit for ten minutes and out for ten minutes; long enough for the seals to get thoroughly hot and then thoroughly cold. This run was continued for 500 hours; then the time switch was disconnected and the lamps were given a continuous run for a further 1,000 hours. During this test none of the lamps failed through deterioration of the vacuum. There were two failures, but these were caused by the filaments coming adrift from the leading-in wires through

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loosening of the paste—purely mechanical faults, having nothing whatever to do with the question of vacuum.

The remaining 28 lamps have been in use intermittently for, perhaps, an additional 500 hours, making an actual burning "life" of about 1,750 hours; but doubtless it is quite as important to note that the lamps were made over six months ago, because, as previously observed, lamps will often lose their vacuum whilst they are merely lying in stock.

An examination of these particular lamps shows that there has been surprisingly little blackening of the bulbs, and the author thinks that it is not generally appreciated how greatly this blackening is dependent on the degree of vacuum maintained.

The conclusions deduced from the test above described have been amply confirmed by several other independent trials, and it is now clear that the Sineplat seals are consistently good when made by hand, whilst preliminary tests with machine-made lamps promise equally satisfactory results.

On referring back to the list of conditions which are set out as the specification of a satisfactory leading-in wire, it is evident at a glance that whilst copper complies with this specification as regards most of the points, the condition as to coefficient of expansion is apparently not met, but the flattening of the wire increases the proportion of surface area to mass, and the strain on the glass due to the expansion of the copper is less at any point when the copper is in strip form than if the copper were a cylindrical wire of equal cross-sectional area.

As the proportion of surface area to mass of copper is increased, so is the cracking strain of the copper upon the glass reduced, and if the copper is flattened below the point of critical thickness, then no cracking will result. For the lead glass usually employed by lamp manufacturers, this critical thickness has been determined by experiment at about 0·1 mm., and with this gauge of copper about 50 per cent. of the seals will crack, but below this gauge—0·075 mm.—no cracking whatever takes place, even though the projecting copper wire be raised to a red heat close up to the glass.

It is believed that a further advantage is gained by flattening the copper, as it is probable that the rolling may force out some of the occluded gases by closing up the inter-molecular spaces, and the strip certainly appears to contain much less occluded gas than cylindrical wire of the same cross-section.

The cheapness of the metal permits of a much larger cross-section being used than would be possible with platinum, and added to this there is the higher conductivity of the copper to assist in keeping the seal cool.

The applicability of the Sineplat seal to X-ray and mercury vapour apparatus may be here suggested, though reports of practical results are not yet available. It can, of course, be used in any of the new metallic filament lamps, in which the relationship between the blacken-

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ing and degree of vacuum seems to be quite as close as in the case of the carbon filament.

The introduction of a substitute for platinum is not likely to result in any reduction in the price of lamps to the public, as any economy that the manufacturer may effect as a result of this should be set off by improving the quality of the lamp in some other respect.

The author can foresee no valid objection to this form of seal, unless it emanates from the scrap-metal merchant who loses a proportion of his trade when platinum made lamps go by the board.

To all others engaged in the industry every detail is welcomed that helps towards efficiency in lamps, the most inefficient of the paraphernalia with which electricians have to deal.

Discussion.

Mr. W. W. Lackie: We are all very much indebted to Mr. Bastian for coming from London to give us this paper. It seems proper that copper should be used as a conductor, and it is astonishing that it has not been tried before. Hitherto it has been thought that bad light is due to defective pressure, but Mr. Bastian has given us another excuse for bad light. It is interesting to note that this system will probably keep the lamp cooler than the present platinum seals. Mr. Lackie.

Mr. A. W. Stewart: I should like to ask Mr. Bastian whether he has carried his experiments further, and has tried the effect of flattening the platinum to see the effect it has on keeping the ordinary platinum lamp right. There is, of course, leakage in glass in all kinds of lamps with platinum, but I wonder if Mr. Bastian has flattened the platinum as well as the copper. Mr. Stewart.

Professor Magnus Maclean: I should like to know whether there is any relation between the breadth of the copper strip and the diameter of the tube in which Mr. Bastian melted the copper strip, and also was the relation the same when he tried the round copper wire in the same manner as the strip inside. Professor Maclean.

Mr. Charles Day: I do not see how Mr. Bastian prevents the oxidation of the copper wires by putting them into a small glass tube. It seems to me that the copper, when exposed to air, will be subject to oxidation. Mr. Day.

Mr. William McWhirter: The strip must be sealed across the lamp, and the flattening must be in one direction. I suppose that is a point with which great care must be taken in sealing, otherwise there will be trouble. Mr. McWhirter.

Mr. Sam. Mavor: I should like to know the composition of the enamelling sealed on to the glass. Mr. Mavor.

Mr. W. T. Evans: In Fig. 4 two wires are shown as bent over and sealed into the glass again, and that seems to me a point where a crack is very likely to start. Mr. Evans.

Mr. C. O. Bastian: With reference to the flattening of platinum, I have tried it, and I have no doubt that it is beneficial; but we Mr. Bastian.

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Mr. Bastian. already have to use such very fine platinum wires that to flatten them will only render them more flimsy and more difficult to work. It is very difficult to work with such fine wires, as they are so very delicate; but still I think that the flattened platinum is better than the ordinary platinum wire. I have tried it in working with a hard combustion tube, in which one cannot, by the ordinary method, seal cylindrical platinum wires. One can seal flattened platinum wires into these combustion tubes, and that indicates that there is a distinct advantage. The hard glass I have spoken of has a much smaller coefficient of expansion than platinum, and it is almost impossible to seal through it by the ordinary method. As to the size of the tube used in the experiment, it was proportionately the same in the flat copper as in the case of the round wire, and the tube was made to fit as nearly as possible on the glass. [Professor MACLEAN: Then the tube must be smaller in diameter?] Yes. I really cannot tell how the oxidation is prevented. It is better to keep the wire flat, but it is not fatal if it is a little twisted, only it looks better, and there is not a great deal of difficulty in doing it. Even with machine-made lamps the wire can be kept in the right position. The enamel used is that used by all lamp manufacturers. The enamel has apparently little to do with the result; it is a mysterious thing, and I am sorry I cannot give any scientific explanation of it, and I do not believe that any one else can. Fig. 4 is shown as a loop lamp. The end of the wire is just fixed into the glass in the same way as the nickel wires which support the filament, and if it cracks it will not go through the glass. A crack would be very unlikely.

Mr. McWhirter. Mr. W. McWHIRTER: It appears that it is necessary to use a wire of a certain diameter so that the compression may be of a certain amount. If a wire half the size was made, one would expect that the occluded gas would be more; it would not be so well squeezed out.

Mr. Bastian. Mr. C. O. BASTIAN: Quite so. I think that probably the explanation is that one increases a large proportion of surface with this fine wire. The diameter increases, and it diffuses through the glass in very minute bubbles, so that it is hardly seen.

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JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

Vol. 39. 1907. No. 186.

Proceedings of the Four Hundred and Fifty-ninth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, W.C., on Thursday evening, May 9, 1907—Dr. R. T. Glazebrook, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on May 2, 1907, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members—

William Collins. | H. Turnbull.
Charles Turnbull. | Duncan Watson.

From the class of Associates to that of Members—

John Reginald Gall.

From the class of Students to that of Associate Members—

Alexander McLean Nicolson. | Francis Percy Seager.

Messrs. C. C. Paterson and V. A. Fynn were appointed scrutineers

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of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Henry Charles Adams.
Colby Topp Tielke Allan.
Gilbert Austin.
William Gregory Chace.
John Cathcart Christie.
John Drennan.
Barker Ellis.
Nils Frenning.
George James Harford.
Joseph Shaw Heath.
Matthew Cochrane Henderson.
Albert Henry Midgley.
Frederick Latour Milne.
Noel Lathrop Murray.
William John Price.
Marcus Pulvermacher.
Alexander Lang Salton.
Duncan Sinclair.

As Associate.

Kenward Herbert Jackson.

The following paper was read and discussed :—

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TELEPHONIC TRANSMISSION MEASUREMENTS.

By B. S. Cohen, Associate Member, and
G. M. Shepherd.

(*Paper read May* 9, 1907.)

Introductory.—The study of telephonic transmission in a scientific manner has advanced very considerably during the last few years.

The necessity for increasing the range over which commercial speech is possible, due to the constant extension of the telephone into remote districts, and also the realisation of the large expenditure involved in line construction and the consequent possibilities for economies, are undoubtedly responsible for this advance. For some time, however, the advance in transmission study has been mainly on the theoretical side, and investigators into the value of inserting inductances into telephone lines, such as Pupin, G. A. Campbell and Hayes, also Kennelly, have elaborated and put into workable form the original deductions of Oliver Heaviside on the transmission of alternating currents of variable frequency over telephone lines.

In order to apply in a practical manner the laws which govern the transmission of telephone waves, it is necessary to have fairly accurate quantitative information regarding the various factors concerned. The latest formulæ for calculating attenuation take into account practically all these factors, and have been proved to give solutions of most of the transmission problems met with in practice, but unfortunately very little is known as to the value of most of these factors.

As an example, what may be called the two fundamental factors in obtaining quantitative transmission results, viz., the average and highest important frequencies to be found in telephone speech waves, have been in the past more or less guessed at, and consequently very little information exists regarding many other factors which depend on them, such as line and apparatus impedances.

The acquisition of any absolutely accurate figures is a matter of extreme difficulty owing to the large number of variables existing, but an endeavour has been made to get data sufficiently accurate for practical application. This has been rendered possible as a result of the introduction of a number of instruments suitable for measuring the various attributes of telephone waves and lines.

The results described in this paper have been obtained in the investigation laboratory of the National Telephone Company, and embody methods of measuring frequency, distortion, attenuation,

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current and power of telephone waves, and also line and instrument impedances.

STUDY OF WAVE-FORM AND DISTORTION.

Use of Oscillograph.—As might be expected, the oscillograph has afforded a great deal of useful information with regard to telephone waves.

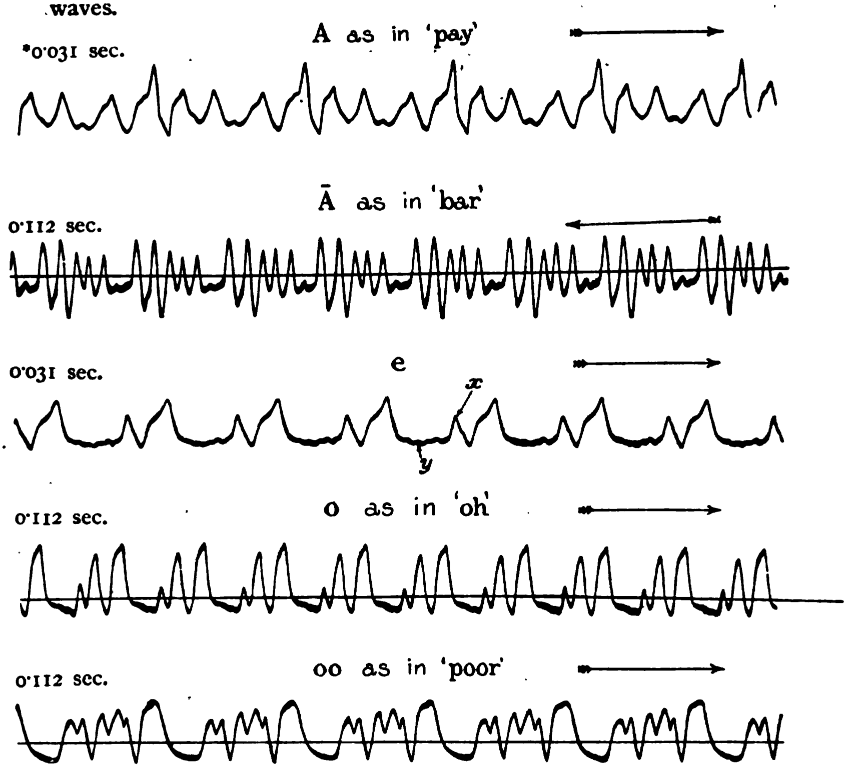

FIG. I.

The instrument used is the high-frequency pattern of Duddell. This instrument has two separate vibrators which can be used in a variety of ways. For investigating the attenuation and distortion of waves over telephone lines, one can be placed at the beginning, and the other at the end of the line.

Owing to the small resistance (about 10 ohms) of these vibrators and their negligible inductance, they have no appreciable disturbing effect on the circuit into which they are introduced.

This oscillograph is used in conjunction with the falling photo-

* The number associated with each oscillogram is the approximate value of the time axis for the portion of the curve shown.

graphic plate arrangement. Owing to the high frequency and general complexity of many of the telephone waves, it is very necessary that the vibrators should be working at their correct damping temperature in order to obtain reliable records. As mentioned by Duddell and others, the best test for correct damping is a square wave produced by interrupting a direct current.

Oscillograms of Speech Waves.—Fig. 1 shows a number of vowel sounds as interpreted by a common battery solid-back transmitter working at normal load. These were continuously sounded into the transmitter mouthpiece.

These vowel sounds are quite characteristic, and can be picked out in many oscillograms of complete words, although they get

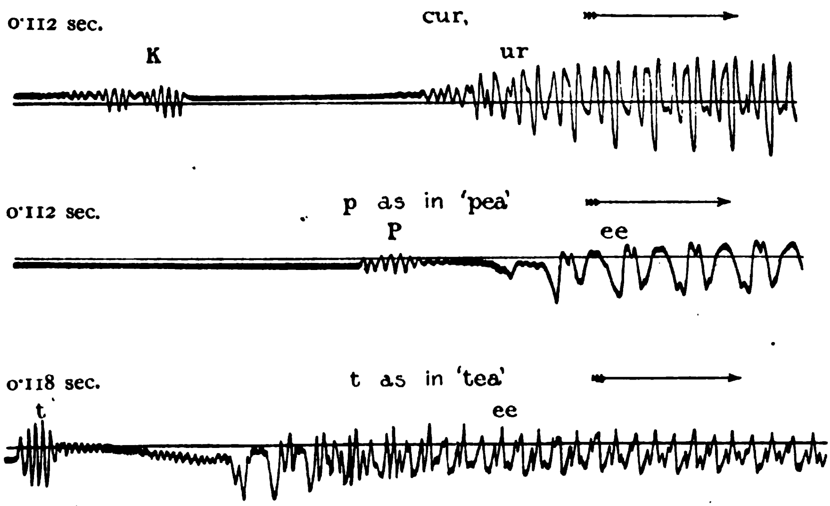

FIG. 2.

altered somewhat in shape by different voices. The small ripple on the flat portion of the E wave marked *y*, for example, is considerably amplified in some voices, and the portion *x* very often disappears completely. The main characteristics, however, remain. E appears to be much the simplest of all the vowel sounds.

The falling-plate camera does not lend itself so readily to the recording of consonants, but by rapidly repeating the consonant and reducing the speed of the falling plate it is possible to obtain satisfactory records.

Fig. 2 shows a number of consonants and words. The beginning and end of each word is indicated. These cases ("cur," "pea," and "tea"), which have all explosive consonants, are interesting. It will be seen that the explosive portion is quite separate and distinct from the vowel portion, being, in some cases, separated by an interval of

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quiescence. The question arose as to why the consonant portion in these cases should be generally of smaller amplitude than the vowel portion, as in the case of the originating sound wave the ear would appear to indicate that the reverse is the case. It was thought that this might be due to the transmitter diaphragm, which in the case of the solid back is somewhat heavy and is strongly damped, and would not therefore respond to the brief consonant portion so well as to the vowel portions. In order to prove this, the same consonants were recorded, using both the solid-back and a lighter diaphragm granular transmitter.

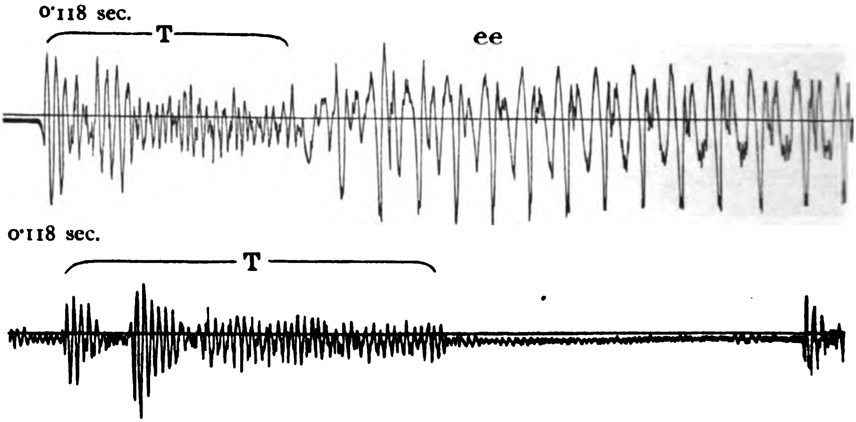

FIG. 3.

Fig. 3 shows the sound "tea" with the light diaphragm transmitter. In this case the consonant portion is nearly of the same amplitude as the vowel portion, the diaphragm is also very little damped and indicates high-frequency vibrations in the interval between the consonant and the vowel which were not shown up by the solid back. Fig. 3 also shows an oscillogram of the consonant portion of "tea" taken by itself. This is clearly a reproduction of part of the preceding figure and helps to prove the accuracy of these oscillograms. It is interesting to note that the tests of the particular light diaphragm-transmitter used gave articulation superior to that of the solid back, although the former transmitter was in some ways inferior to the latter.

FIG. 4.

It may be of interest to mention that the most efficient sound from the point of view of amplitude is the "oo" vowel sound as in poor, whilst the least efficient sounds are the consonants "s" and the rolled "r"; the "r," which is of very high frequency, is depicted in Fig. 4.

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Change in Wave-form in Transmission.

The oscillograph is obviously specially suited to the investigation of the attenuation and distortion of waves over telephone lines, and particularly to the latter.

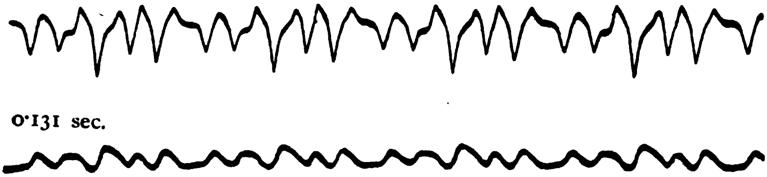

Fig. 5.

Fig. 5 shows the attenuation and distortion of a fairly complex sound wave (singing "la") over a 16-mile cable line. The cable in this case was equivalent to one with 17·6 miles of 20-lb. conductors, and the transmission over this length of line is very good indeed.

On analysing the received wave it is found that everything above the seventh harmonic seems to have practically been wiped out, and this harmonic represents a frequency of 980 ∿.

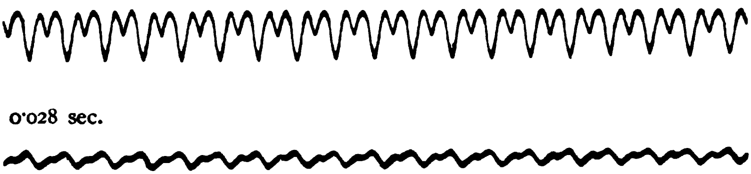

Fig. 6.

Fig. 6 shows a note sung by a girl in a high tone, which was taken as representing the upper limit for speech frequency. The line in this case was 16·6 miles of 20 lbs. On analysing these curves the highest frequency left prominent in the received wave was 3,000 ∿. This is a very high figure, and does not necessarily represent a frequency that matters, first, because the fundamental was exceptionally high, and, secondly, because the speech limit is not reached until about 50 miles of 20-lb. cable is in circuit; unfortunately we have not found it possible to obtain an analysable record over this mileage with the oscillograph.

The analysis of the two waves in Fig. 5 brings to light the fact that the attenuation of the current behaves in a curiously fluctuating manner as the frequency increases. The following table gives percentages of received currents for the various harmonics ;—

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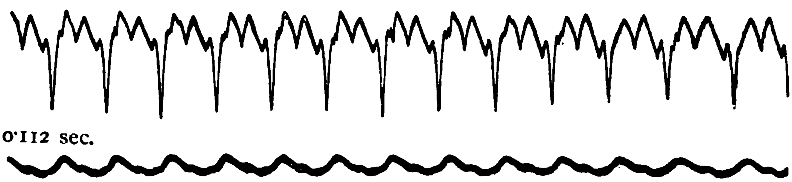
Harmonic.	Percentage received.	Harmonic.	Percentage received.
1 (Fundamental)	81·0	9	25·0
2	47·0	10	25·0
3	57·0	11	81·0
4	46·0	12	13·0
5	41·5	13	2·5
6	28·0	14	15·5
7	25·0	15	4·0
8	30·0		

The big rise at the eleventh harmonic is very noticeable.

A further example of this effect is apparent in the wave-forms of



0·112 sec.

FIG. 7.

Fig. 7, which represent a singing "oo" sound on 30 miles of cable. Analysis up to the eleventh harmonic shows the following percentages received :—

Harmonic.	Percentage received.	Harmonic.	Percentage received.
1	34·3	7	6·3
2	16·7	8	1·5
3	6·0	9	33·0
4	5·0	10	16·4
5	1·0	11	8·2
6	7·3		

The ninth harmonic is the notable one in this case, and would have a frequency of about 2,295 ∿. Such analyses as the above are, of

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course, somewhat rough affairs, owing to the difficulty in obtaining clearly defined enlargements of attenuated wave negatives; it is also an extremely laborious business.

The absence, unfortunately, of any precise data regarding the terminal conditions of the circuit when these oscillograms were taken, renders it impossible to explain the phenomena theoretically. That such an occurrence is in some degree possible, however, may be demonstrated by taking an arbitrary complex E.M.F., and supposing this to be impressed upon a circuit of known electrical constants. Thus, let the following—

$$E = 100 \sin pt + 75 \sin (2pt - 45) + 50 \sin (5pt + 30),$$

with a fundamental of 200 ∿, be the actual potential difference at the sending end of a cable line whose data are :—

Length	15 miles ;
Capacity	0·054 m.f. per mile ;
Resistance	85 ohms "
Inductance	0

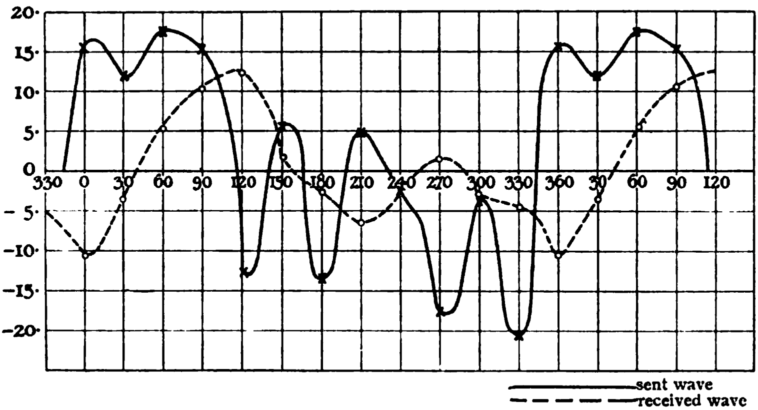

FIG. 8.

and which is terminated by a piece of apparatus, such as a telephone instrument of, say, 0·18 henry and 200 ohms.

Fig. 8 shows the above function plotted out through a complete period, both for the beginning and end of the circuit. In this theoretical example the percentages of received current for the three harmonics present are respectively—

1st	57·4 per cent.
2nd	71·5 "
5th	14·4 "

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Oliver Heaviside deals with this matter at some length in his collected papers, Vol. II., and shows by means of the equation for the receiving end impedance, that the latter passes through successive maxima and minima values with increasing frequency. These fluctuations become less and less marked, and finally disappear at high frequencies. What precisely the practical effect on transmission is of this special reinforcement and diminution of certain tones we cannot at present say. The causes tending towards distortion are so many and varied that perhaps the resultant effect is not so strongly felt as might otherwise be the case. At all events, Heaviside's remarks regarding the instinctive quality of the human ear for recognising what must in reality be the merest phantoms of speech vibrations, appear to be pretty well borne out in practice. Volume is the prime necessity; articulation is, comparatively speaking, of secondary importance. The subject of line resonance (if that term may be applied) seems, however, to be one worthy of closer investigation.

As previously mentioned, figures for the highest frequency met with in speech waves, which must be retained in order to obtain intelligible speech, are of great importance, and although the oscillograph may help to obtain some idea on this subject, this method is necessarily exceedingly complex and laborious, and involves the likelihood of considerable error, although it must be borne in mind that any absolute figures are out of the question, as the point at which articulation becomes so bad as to render the speech unintelligible involves the personal equation to a considerable extent.

Highest Important Frequency in Telephone Waves.

Some tests carried out on loaded lines led to an interesting method of ascertaining the highest important frequency in articulate speech. If the spacing—*i.e.*, distance apart—of loading coils is increased, and at the same time the amount of inductance per mile inserted is unchanged, the attenuation constant also increases gradually, and at one particular spacing increases to an enormous extent.

Fig. 9 shows curves for the variation of attenuation constant with spacing for frequencies of 800 and 1,600 $\sim$. These curves were calculated from formulæ by G. A. Campbell (see Appendix), and have been confirmed by tests made with a sine-wave alternator.

As the articulation of a received telephone wave depends to a very great extent on the attenuation of the harmonics present, it was thought that the application of the arrangement just referred to would help to settle the question as to which frequencies determine by their presence or absence the difference between articulate and inarticulate transmission.

A series of articulation observations were consequently made on 20 miles of cable for increasing spacing intervals with a constant load of 0·17 henry per circuit mile and commencing with a distribution of 1 load per mile.

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It was found that a 2-mile load was very slightly inferior to the unloaded line of equivalent speaking volume, but still gave excellent commercial transmission. This indicates that harmonics above 1,600 ∾ may be dispensed with (see Fig. 9).

With 3-mile distribution the articulation was commercial, but

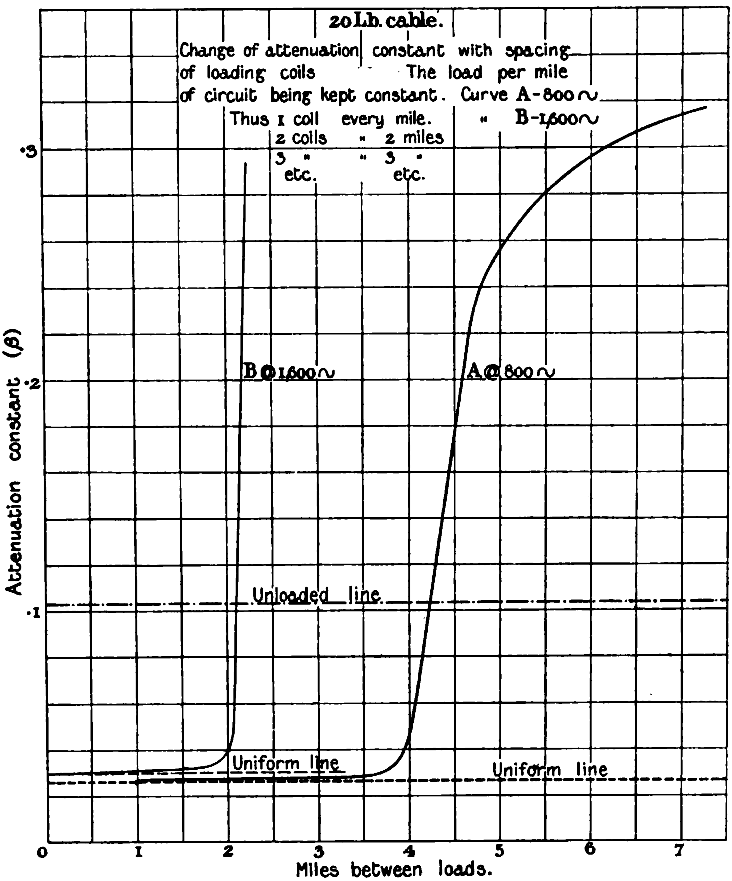

FIG. 9.

decidedly inferior to the unloaded line. The critical frequency for this disposition of the load was about 1,100 ∾, and it is thus apparent that harmonics between 1,100 ∾ and 1,600 ∾ are valuable.

For 4-mile intervals speech became quite impossible, although the volume was still quite considerable, and we must therefore conclude that the highest indispensable frequency lies between 800 and 1,100 ∾, and also that it is desirable to retain something higher than 1,100 ∾

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for really high-grade transmission. Probably 1,500 $\sim$ would be quite a satisfactory figure to base calculations on.

Pupin and other writers use 750 to 800 $\sim$ for many transmission calculations. It is important to note that this represents a fair average frequency, as damping constants calculated with this value can be obtained experimentally when using actual speech waves.

Relationship between Sent and Received Waves on Short Cable Lines.

On short cable lines, and, provided that some amount of terminal impedance exists at both ends of the line, the relationship between the sent and received currents is somewhat peculiar. Fig. 10 shows the wave at the beginning and end of a line equivalent to 2·2 miles of 20-lb. cable, and in this case the receiving end wave is of considerably greater amplitude than the wave at the transmitting end.

The wave in this case was produced by whistling into the transmitter. The effect is considered further on in connection with telephone current measurements.

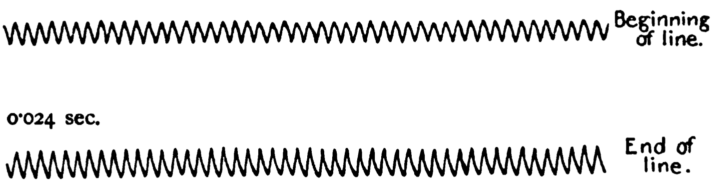

Fig. 10.

Effects Produced by Opening and Closing Receiving Ends of the Line.—Fig. 11A shows the effect on the transmitted wave when opening and closing the receiving end of a line consisting of 2 miles of 20-lb. cable. With this short line the cable current passing from the A to the B wires, by virtue of their mutual capacity, is smaller than the total current flowing when the far end is closed. The variation in wave-form is also very noticeable. When, however, the line is 7·5 miles of the same cable, the current is actually greater when the far end is open than when it is closed (see Fig. 11B). Lastly, when the line gets beyond a certain length, the effect on the amplitude at the transmitting end by opening and closing the receiving end is negligible.

Fig. 11C shows the effect with 20 miles of 20-lb. cable.

These phenomena, which are dealt with further in another part of this paper, are due to the action of the terminal impedance, and may prove of considerable importance to the telephone engineer, as they can be varied to a great extent by varying the impedances of the terminal apparatus. With long lines, the tendency is for the impedance at the sending end to become a constant quantity, not varying appreciably with the length, and the reaction of the

terminal apparatus becomes evident only to a very small degree at the sending end.

Current Measurers and Measurements.

Two forms of apparatus have been used, the barretter and the thermo galvanometer.

The *barretter*, otherwise termed the *bolometer*, is a device for measuring small alternating or fluctuating currents. It consists of a conducting wire or filament, which has a high temperature coefficient

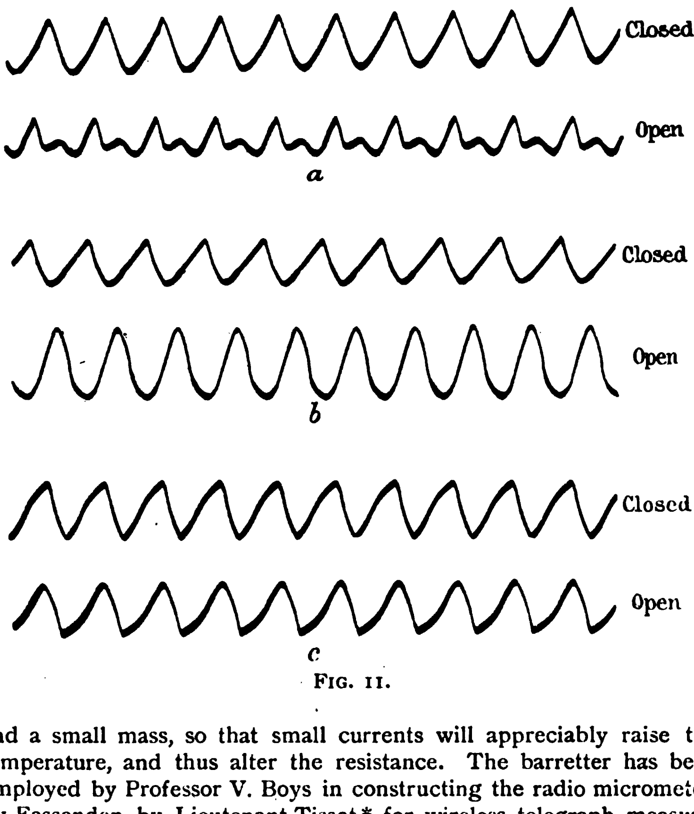

Fig. 11.

and a small mass, so that small currents will appreciably raise the temperature, and thus alter the resistance. The barretter has been employed by Professor V. Boys in constructing the radio micrometer, by Fessenden, by Lieutenant Tissot* for wireless telegraph measurements, and lastly, by A. E. Kennelly.†

Professor Kennelly used barretters made of very fine platinum wires. Owing to the extreme delicacy of these wires, Dr. Hayes, of the American Telegraph and Telephone Company, carried out investigations to discover a barretter more suitable for work outside the

* *Journal Institution of Electrical Engineers*, vol. 36, p. 468.
† *Transactions of Internat. Elect. Congress*, St. Louis, 1904, vol. iii., p. 414.

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laboratory. He found that small low-voltage telephone switchboard lamps gave satisfactory results, and this has been confirmed by experiments carried out by us.

The best lamp we have found for this purpose is a special pattern 24-volt curl filament lamp for telephone switchboard use.

The curve (Fig. 12) shows the relationship between the current and the resistance using this lamp. Following the usual law, the greatest resistance variation with these carbon filaments occurs when using small currents.

Experiments have been tried to increase the sensibility of the filaments by overrunning the lamp for some hours, and thus reducing the mass; but although great sensibilities have been obtained, it was found impossible to make a number of barretters

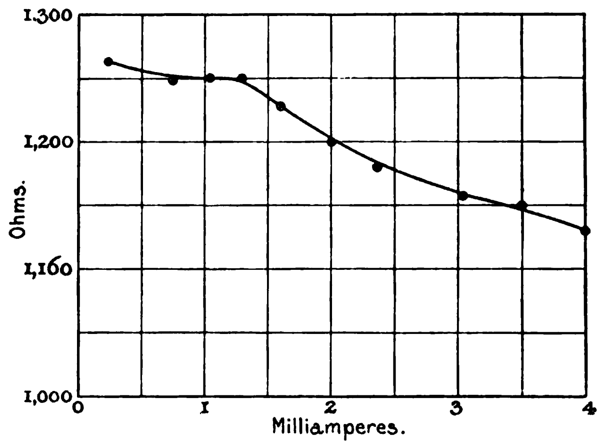

FIG. 12.

exactly similar to another. The filaments always reduce at their weakest point, and, in consequence, although two filaments could be obtained having the same sensibility, the time of response to a change of current, varied, and with the null method of working barretters described further on, this gave rise to trouble.

NULL METHOD OF WORKING.

The arrangement of barretters shown in Fig. 13 has been adopted after considerable experiment.

This arrangement enables measurements of apparatus and line impedance, capacity, etc., to be carried out, the result being obtained in actual ohm values and with very little more trouble than that involved in taking an ordinary resistance measurement with direct current.

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The figure shows a source of alternating current such as a sine-wave alternator connected to two branch circuits, in one of which a variable resistance box A is inserted. The other arm has the apparatus or line to be measured, inserted at B.

The barretters are connected through adjustable resistances and batteries to the galvanometer, which can be of any pattern.

The shunt, which for general work can be varied from 10 to about 500 ohms, helps to eliminate errors due to the impedance of the barretter circuits.

The barretters are first balanced in resistance by the adjustable resistances until the galvanometer indicates no deflection. The alternating current is then applied, the circuit being through the condensers and round the barretters. This current is stopped from passing from one branch into the other, *viâ* the galvanometer, by the four choking coils. When the resistance box in A is adjusted so that no deflection is indicated on the galvanometer, then the resistance unplugged in A, after making allowance for the impedance of the shunted barretter

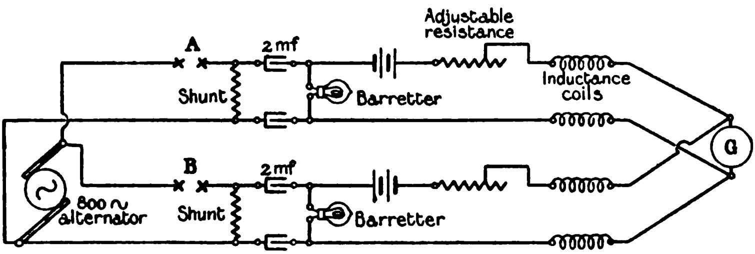

FIG. 13.

circuits, represents the impedance of B, and if the two barretters are not exactly similar, a second reading can be taken with A and B reversed and the mean taken. Variations in barretter resistance caused by temperature changes have no effect on this arrangement, as the barretters are fixed close together and compensate each other.

CORRECTIONS TO BE APPLIED WHEN MEASURING EFFECTIVE RESISTANCE INDUCTANCE, OR CAPACITY, BY THE BARRETTER.

Inductance.—Let R be the balancing resistance unplugged from the box, and r the total resistance of barretter and shunt, and R_0 the effective resistance of the apparatus measured (includes true resistance and iron losses).

Then—

$$I^2 = R^2 + 2r(R - R_0),$$

provided that the impedance of circuit on galvanometer side of barretter is high enough to be negligible, and that both circuits are fed with the same voltage.

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From the equation it is evident—

(1) If r is small enough, R is the true impedance. In no other case is this so.

(2) In some cases R_0 will be small compared with the reactance, and then—

$$I^2 = R^2 + 2 r R.$$

(3) By varying r and taking (two) readings it is possible to eliminate I and obtain R_0. Thence the impedance and inductance can be obtained.

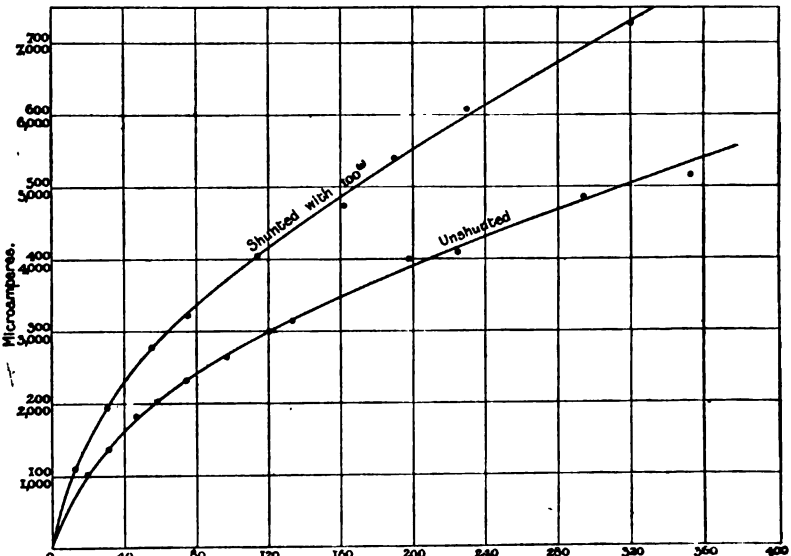

FIG. 14.

By taking $x r_1 = r_2$, then—

$$R_0 = \frac{R_2^2 - R_1^2 + 2 r_1 (x R_2 - R_1)}{2 r_1 (x - 1)}.$$

Condenser Measurement.—In this case the same formula will hold, R_0 being the effective insulation of the condenser. It includes dielectric losses. As a rule these are negligible, and we get—

$$I^2 = \left(\frac{1}{cp}\right)^2 = R^2 + 2 r R.$$

Deflectional Use.—In this method only one barretter is actually used, the other being merely left in the circuit to balance the one used, both for atmospheric temperature variations and for resistance. One of the

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barretters is inserted in the circuit in which the value of the current strength is required, and the change in its resistance due to this current causes the galvanometer to deflect. The instrument then becomes practically a hot wire ammeter. It has this disadvantage that it is somewhat difficult to calibrate. The simplest method of calibrating is to pass an alternating current through the barretter in series with a known variable resistance, and to measure the P.D. across the latter with an electrostatic voltmeter. Fig. 14 shows such a calibration curve. It will be seen that 60 micro-amps. correspond with 10 divisions deflection (about 5 mm.). This is about the minimum measurable.

The sensibility of the barretters used in relation to telephone currents is such that fairly small non-inductive shunts can be used to eliminate the effect of the barretter impedance.

When testing telephone lines, ordinary telephone repeating coils, etc., can be inserted in order to give the ordinary terminal conditions met with in practice.

Thermo Galvanometer.

Duddell's thermo galvanometer has been used for current measurements. It has many advantages, and for deflectional methods is probably unrivalled if the source of power is absolutely steady, but it cannot be satisfactorily employed with transmitters in circuit owing to their variability, even although the sound impressed is quite steady. The barretter is somewhat better for this purpose, as the mass of the filaments employed is greater than that of the heaters used in the thermo galvanometer of the same relative sensibility, and consequently the time of response to a current variation in the thermo galvanometer is smaller, and the sensibility to momentary disturbances thus much greater. This comparison, of course, only refers to the actual apparatus employed, and it should be quite possible to alter the time of response of the thermo galvanometer, and thus reduce its sensibility to small disturbances. Some of the measurements referred to in the ensuing pages have been made with the thermo galvanometer.

Current Measurements.

The relationship between the currents C_s and C_r at the beginning and end respectively of different lengths of telephone line can be readily measured with two barretters. As mentioned before, the relationship is complicated by the addition of terminal impedances at either end of the line. Fig. 15 shows this current relation plotted for various lengths of 20-lb. conductor cable equipped with ordinary telephone instruments at either end.

It will be seen that up to nearly 6 miles the received current is greater than the sending current. At about 20 miles the sending end current, which has up to this length been mostly increasing, has practically reached a constant figure, and is after this very little affected by any further increase in the length of line.

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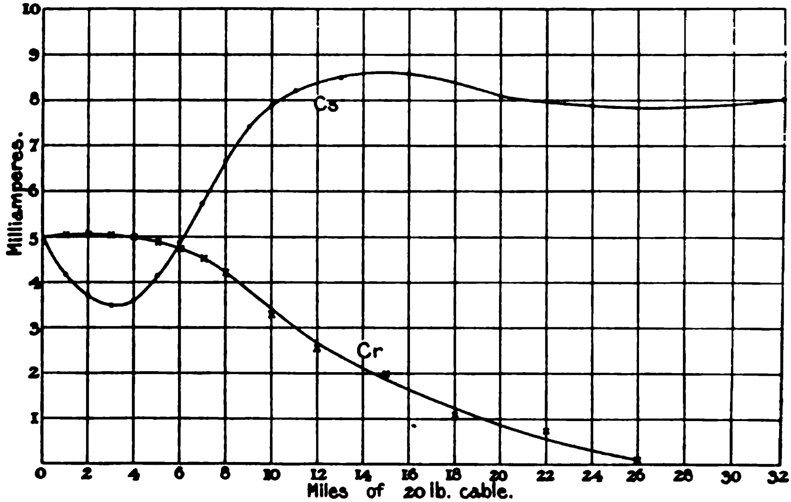
Milliamperes.
Cs
Cr
Miles of 20 lb. cable.

FIG. 15.

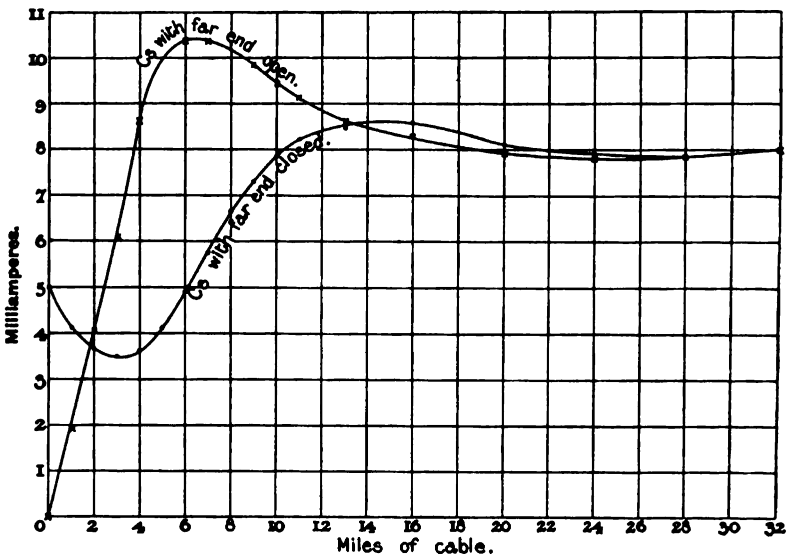
Milliamperes.
Cs with far end open.
Cs with far end closed.
Miles of cable.

FIG. 16.

The necessity for allowing for the action of the terminal apparatus is well emphasised by these curves.

Fig. 16 shows the relationship between the current at the sending end of the line when the receiving end is open and closed for various lengths of line. The cable line used in this case had 20-lb. conductors, and the line was terminated as before at either end by ordinary telephone instruments.

It will be noticed that at about 20 miles and upwards the current flowing into the cable is practically unaffected by the opening and closing of the receiving end, and that this also happens at about 2 miles. The current used for the above tests was at 800 ∾, and practically sinusoidal in form.

Determination of Damping Constants on 20-lb. Cable.

This was done by actuating an ordinary telephone transmitting circuit by a steady musical note, and then observing the ratio of sending and receiving currents on a varying length of cable, which could either be shorted at the far end, or closed through a known impedance. The appended table shows the relation found between the actual Cs/Cr, and the hyperbolic function cosh (la), which is the calculated ratio of Cs to Cr. (Where *l* is the length of line and *a* the complex attenuation constant see Appendix.)

Miles.	$\frac{Cs}{Cr}$	∾	Cosh (la).	Error.
		Far end short-circuited.		
5	1·065	792	1·0287	—3·5 per cent.
10	1·385	783	1·3740	—0·8 ,,
15	2·310	763	2·3100	0·0 ,,
	Far end closed through impedance 22 ohms 0·15 henry.			
10	1·302	792	1·2400 *	—4·8 per cent.

Considering the irregularity in wave-form of a microphone produced current, the agreement between theory and practice is very fair. The telephone currents actually used were of the order of those commonly observed on standard common battery junction circuits.

By roughly balancing up a treble C singing note sung into a transmitter against a sinusoidal alternating current of similar frequency placed direct on the junction at the transmitting end, and then measuring the latter current on the thermo galvanometer, a general idea of the magnitude of the talking current is obtained.

* This figure is the ratio of receiving end to sending end impedance.

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At the sending end of the line and at the junction side of the repeating coil, a current of about 5 m.a. and a P.D. of about 3·5 volts was observed. In the receiving instrument secondary, about 2·4 m.a. with 10 miles, 0·53 m.a. with 30 miles, and 0·24 m.a. with 40 miles of 20-lb. cable, were measured. There were local subscribers' loops of 150 ohms resistance in connection with the above circuit.

Sinusoidal Current Producers.

Considerable difficulty has been experienced in obtaining a steady sinusoidal current of the frequencies required for telephone measurements.

Arrangements depending on the reaction of transmitters and receivers have been tried, but without satisfactory results, as the waves are not by any means sinusoidal, and it is impossible to obtain the requisite steadiness. At present there appears to be no machine of a reasonably small size on the markets for which the makers will give a sufficiently definite guarantee at the frequencies required.

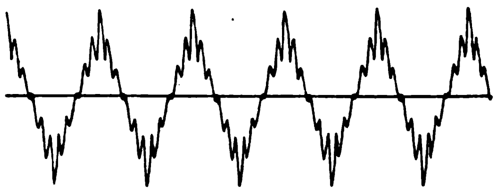

Fig. 17A.

As an example of the difficulty experienced, Fig. 17A is an oscillogram taken with such a machine of the wave-form on a non-inductive load. The suppliers were under the impression that this machine would give a closely sinusoidal wave-form. The machine used at present is a small inductor alternator, having an armature built up of ordinary slotted stamping, and gives a frequency of 800 ∿ at

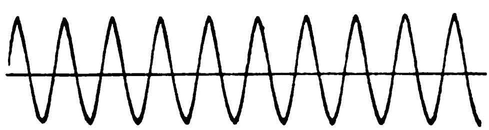

Fig. 17B.

960 r.p.m. The output is small, but the wave is a very fair one, considering that no special shaping of the teeth was attempted. Fig. 17B is an oscillogram from this machine.

Wave Filter.

In order to purify the wave-form for very precise measurements the peculiar property of the periodic loaded line already referred to

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and mentioned by G. A. Campbell * in his paper on loaded lines has been utilised. By building up an artificial line, consisting of four or five sections, each associated with a condenser, inductance and resistance coils, it is found possible practically to abolish all upper harmonics and to leave the fundamental frequency desired. A wave filter of this description requires no tuning, and is safe over a considerable range of frequency, but naturally introduces a certain amount of loss.

Power Measurements.

The measurement of the energy absorbed by telephonic apparatus under working conditions presents considerable difficulty. The amount of energy is frequently exceedingly small, perhaps a few microwatts only, and is always a very variable quantity. At the date of writing this paper we are unaware of any instrument directly indicating small fractions of a watt, which could be included in the receiver circuit of a telephone without radically changing the circuit conditions. An ironless two-coil wattmeter of the requisite sensibility offers a series impedance of many thousand ohms, and is, of course, quite inadmissible on that account. A thermal method seems to be the only alternative, and the hot-wire voltmeter method, due, we believe, to Mr. M. B. Field, was employed with some success. The theory of this arrangement is given in the Appendix, and the connections are shown in Fig. 18. The instrument used to indicate the vector sum and difference of potential was a Duddell thermo galvanometer, operating with a 100-ohm heater. As only one such instrument happened to be available, it was necessary to employ a reversing switch to change the sense of the P.D. component. Switching arrangements were also provided to permit of current and P.D. measurements to be made independently, and to calibrate the galvanometer when required, by continuous current. Some difficulty was experienced in finding a suitable transformer for this work, presumably on account of complications occasioned by iron losses at the moderately high frequencies used to imitate speech currents, and also by variations of transformation ratio. An air-core transformer would probably have been a cumbrous and costly piece of apparatus, for it had to be borne in mind that, as the secondary winding was across the telephone circuit, a high inductance was imperative. A toroidal coil having a core composed of iron wire of about No. 40 S.W.G. was finally adopted. The dimensions of this core were approximately 11½ cms. external diameter, sectional area 7 sq. cms., depth 5 cms. The two windings had about 2,000 turns and 100 turns respectively, and the ratio of transformation experimentally determined ranged from 96·5 to 19·3, according to the number of secondary turns employed. A series of preliminary tests was made with the above described combination, using artificial loads made up of known non-inductive resistances, capacities, and inductances; and the results, though not of a very

* *Phil. Mag.*, vol. v., 1903, p. 313.

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high order of accuracy, were yet encouraging when the difficulties were considered. The thermo galvanometer, as mentioned previously, when worked up to its greatest sensibility, was found to be extremely sensible to outside disturbances of various kinds, and much trouble was

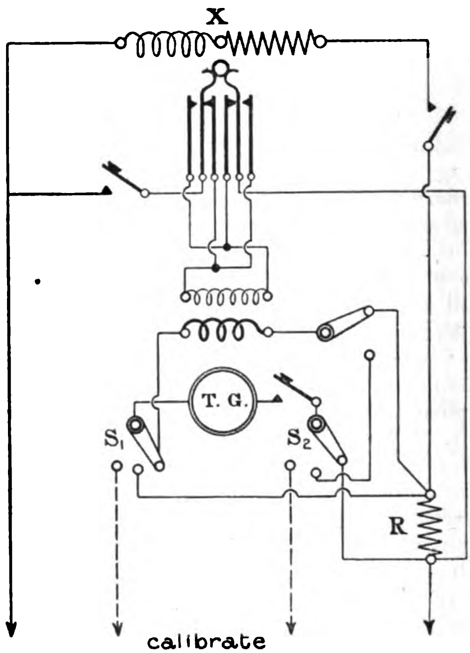

FIG. 18.

experienced from leakage and capacity currents in the test circuits. When the frequency is even no higher than 800 ∿ the term "non-inductive," as usually applied to resistances, requires qualification; and unless care be taken very erroneous conclusions may be arrived at. Some results using this apparatus are appended :—

Apparatus Tested.	Current.	Actual Watts.	Apparent Watts.	Power Factor.	Effective. L.	Effective. R.	∿
C.B. Receiver	0·00695	0·00858	0·01435	0·600	0·0425	165	825
120-ohm Receiver ...	0·01160	0·02220	0·02930	0·760	0·0280	165	825
120-ohm Receiver and Induction Coil ...	0·00220	0·00139	0·00247	0·562	0·0650	227	825
C.B. Repeater, Type 25 C., with 150-ohm Subscribers' Line...	0·00208	0·00149	0·00218	0·685	0·0690	320	800

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Test of sending end impedance of 30 miles of 20-lb. paper telephone cable, far end open :—

Current.	Watts.	Power Factor.	Phase Angle.	Impedance.	∾
0·00658	0·0163	0·71	44° 48′	552 ohms	810

This is in good agreement with the theoretical estimate of the impedance of this class of cable, viz., 550 ohms and phase angle 45°. All the above-described tests were made with current supplied by the small inductor alternator previously referred to using its natural wave-form.

In these days of the sovereignty of the two-coil wattmeter one scarcely cares to mention the three-voltmeter method, but as a matter of fact this method was found very convenient for certain measurements of the efficiency of induction and repeating coils. The instrument used was an Ayrton-Mather electrostatic voltmeter having a readable range of about 1–10 volts. By switching over quickly into the requisite positions on the circuit quite consistent readings could be obtained.

An excellent point in favour of this voltmeter in connection with telephonic measurements is its negligible working current. It is a little disconcerting to find that the efficiency of conversion between the primary and secondary circuits of a telephone is of the order of 1 per cent., though when used as an ordinary transformer, at about 800 ∾ passing a current of a few milliamperes, the efficiency of the best type of induction coil is quite high, viz., about 72 per cent. The low efficiency in the former case is, of course, due to the large constant component of the current in the primary. A slightly higher efficiency was found for a coil of the toroidal pattern, but, unfortunately, improvements in the direction of a closed magnetic circuit have not so far proved feasible for induction coils.

We have also applied the three-voltmeter test to the determination of cable constants at working frequencies. This method (see Appendix E) seems to have been used to some extent by Dr. Breisig, of the German Telegraphs, who, however, employed apparatus of a special kind to measure the phase of the entering current. In the experiments made in the National Telephone Company's laboratory the cable line to be tested was connected to the high-frequency generator through non-inductive resistances inserted in either leg, and the watts, current, and voltage observed when (1) the distant end was open, and (2) when same was short-circuited. From these two sets of correlated readings the impedances at the sending end are specified completely as vectors, and thence the four constants R, L, S, and C may be deduced. As experiments in this direction are at present only in their initial stages, we are unable to say much about them.

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Cables of the ordinary telephone types are notable chiefly for their high copper resistance, very small inductance, and high insulation; consequently the evaluation of the inductance and leakage constants depends on the possibility of very accurate phase measurements correct to a few minutes. This is a matter of considerable difficulty, and the examples given below must be regarded as trial endeavours :—

Line.	Impedance.		R.	C.	S.	L.	∾
	End open.	End S.C.					
10 m. 20-lb. Standard...	495 – 54° 20′	657 – 29° 18′	82·4	0·0540	$7{\cdot}12 \times 10^{-6}$	0·00145	750
10 m. 20-lb. Artificial...	498 – 51° 28′	644 – 36° 6′	94·0	0·0624	—	0·00020	750

Currents used were from 6 to 10 m.a. with P.D.s of 2 or 3 volts. The figures for resistance and capacity differ very slightly from what would be obtained by direct-current measurements.

The constants L and S in the case of the 20-lb. cable are possibly doubtful, owing to the phase-measuring difficulty referred to, but there is good reason to believe that there is a very considerable reduction in the effective insulation of paper cables at telephonic frequencies. It is hoped that further investigation will lead to more precise results.

Telephone Line Equivalents Experimentally Obtained by Means of Voice Tests.

The National Telephone Company were perhaps the first English telephone authorities to obtain any very accurate figures for the relative transmission values of various types of telephone lines.

A series of attenuation constants for all the types of lines in use in this country were calculated in July, 1904, from the now well-known formulæ, taking into account the resistance, capacity, inductance, and average leakage, and the results were embodied in a table of equivalents, taking a 20-lb. low-capacity cable as a standard. The results were experimentally verified in December and January, 1904 and 1905, the method for verifying being a simple one. This table of equivalents has already been published in Mr. Gavey's presidential address.

Talk is transmitted over two lines alternately, using the same telephone instruments for both lines, one of which is a variable standard line and the other the actual line under test. The variable standard, which in the laboratory is an actual telephone cable capable of being varied in length from 0·1 to 52 miles, and which for portable purposes consists of an artificial cable calibrated against the laboratory standard, is adjusted until the talk over both lines as judged by the ear is balanced, and the ratio of length of non-standard to length of standard gives the equivalent.

With practice, variations of very small fractions of a mile can be detected.

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An endeavour has been made in this paper to apply to telephony the systematic methods of research and investigation which have practically developed the heavier branches of electrical engineering into exact sciences. The subject is a large one, the conditions generally exceedingly complex and variable, and the literature dealing with the experimental side decidedly scanty. Of mathematical discourses on wave propagation in cables, etc., there are plenty, but of a nature which does not appeal to the engineer. Professor Kennelly has so far perhaps made the most practical effort to grapple with the theory, and all interested in this form of A.C. transmission owe a debt of gratitude to him.

In conclusion the authors of this paper would ask the electrical engineering profession not to regard too severely any looseness of expression and nomenclature to be found therein, as at the present moment the subject is scarcely more than just opening up.

They desire also to express their indebtedness to the National Telephone Company, and especially Mr. Gill. It is their policy in providing at considerable expense the necessary apparatus and facilities that has enabled the authors to carry on the investigations embodied in this paper. Thanks are also due to Messrs. Aldridge, Coote, and Styles, who have rendered valuable assistance in many of the investigations.

APPENDIX.

A. Theory of Transmission.

Considering the current and potential at any point at distance x from the receiving end of a line, having resistance R, leakage conductance S, capacity C, and inductance L, all per unit of length, we have for the fundamental equations of propagation where i and E are current and potential respectively—

$$\frac{\partial E}{\partial x} = (R + j p L)\, i$$

$$\frac{\partial i}{\partial x} = (S + j p C)\, E$$

or—

$$\frac{\partial E}{\partial x} = \dot{I}\, i \qquad \qquad (1)$$

$$\frac{\partial i}{\partial x} = Y E \qquad \qquad (2)$$

writing $\dot{I}$ and Y for the impedance and admittance factors. By differentiation and substitution—

$$\frac{\partial^2 E}{\partial x^2} = \dot{I}\, Y E \qquad \qquad (3)$$

$$\frac{\partial^2 i}{\partial x^2} = \dot{I}\, Y i \qquad \qquad (4)$$

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The general solution for E is—

$$E = A e^{ax} + B e^{-ax} \quad \ldots \ldots \ldots \quad (5)$$

where A and B are arbitrary and $a^2 = \dot{I}\,Y$.

Whence for $i = \frac{1}{\dot{I}} \frac{\partial E}{\partial x}$ the solution is—

$$i = \frac{a}{\dot{I}}(A e^{ax} - B e^{-ax}) \quad \ldots \ldots \ldots \quad (6)$$

The terminal conditions are involved in the coefficients A and B.

Equations (5) and (6) may be expressed in terms of the hyperbolic functions as follows :—

$$E = (A + B)\cosh ax + (A - B)\sinh ax$$

$$i = \sqrt{\frac{Y}{\dot{I}}}\left[(A - B)\cosh ax + (A + B)\sinh ax\right]$$

$\frac{E}{i}$ = an impedance, say $\dot{I}_1$—

$$= \sqrt{\frac{\dot{I}}{Y}}\left\{\frac{(A + B)\cosh ax + (A - B)\sinh ax}{(A - B)\cosh ax + (A + B)\sinh ax}\right\}$$

$$= \sqrt{\frac{\dot{I}}{Y}}\left[\frac{\frac{A + B}{A - B} + \tanh ax}{1 + \frac{A + B}{A - B}\tanh ax}\right]$$

or say—

$$I_1 = \sqrt{\frac{\dot{I}}{Y}}\left\{\frac{K + \tanh ax}{1 + K\tanh ax}\right\} \quad \ldots \ldots \ldots \quad (7)$$

It follows that at—

$$x = 0, \quad I_1 = \sqrt{\frac{\dot{I}}{Y}} \cdot K$$

$$x = \infty, \quad I_1 = \sqrt{\frac{\dot{I}}{Y}}$$

Using Dr. Kennelly's notation, we have—

$$K\sqrt{\frac{\dot{I}}{Y}} = Z_r$$

for the receiving instrument impedance, and—

$$\sqrt{\frac{\dot{I}}{Y}} = Z_0$$

for the line impedance, whence—

$$K = \frac{Z_r}{Z_0},$$

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and (7) then becomes—

$$I_1 = Z_s = Z_0 \left\{ \frac{\frac{Z_r}{Z_0} + \tanh l a}{1 + \frac{Z_r}{Z_0} \tanh l a} \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

the impedance *at* the sending end for *any* length of line l.

Writing E_r and i_r for the values at the receiving instrument, and if V = impressed voltage at the transmitting end—

$$\frac{i_r Z_r}{V} = \frac{A + B}{(A + B)\cosh l a + (A - B)\sinh l a}$$

Consequently—

$$i_r = \frac{V}{Z_r \cosh l a + Z_0 \sinh l a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The denominator of the last expression is termed the receiving end impedance, and is the criterion for the magnitude of the received current for any specified impressed E.M.F.

For the initial current we, of course, have—

$$i_s = \frac{V}{Z_s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

These expressions are now well known, and can without difficulty be applied to numerical calculations, no easy matter in the case of the more expanded formulæ of Heaviside.

Some confusion seems to exist as to the title of the constant a. Dr. Kennelly styles it the attenuation constant, a term applied (we consider with more justification) by some other authorities to the real part of a.

Since a is a complex quantity equivalent to—

$$\alpha + j\beta$$

say, it follows that—

$$\alpha^2 + \beta^2 = (R^2 + p^2 L^2)^{\frac{1}{2}} (S^2 + p^2 C^2)^{\frac{1}{2}}$$
$$\alpha^2 - \beta^2 = R S - p^2 L C$$

and $\therefore$

$$\alpha = \sqrt{\tfrac{1}{2}\sqrt{(R^2 + p^2 L^2)(S^2 + p^2 C^2)} + \tfrac{1}{2}(R S - p^2 L C)}$$
$$\beta = \sqrt{(\ . \ . \ . \ \text{do.} \ . \ . \ . \ ) - (\ . \ . \ \text{do.} \ . \ . \ )} \quad . \quad . \quad (11)$$

It is the quantity α which is of such immense importance to telephone engineers, since it affords a measure of the decay of the transmitted impulses. In practice α may vary from about 0·0022 for the heaviest type of copper aerial construction to perhaps 0·22 for the lightest gauge of underground cable at present used, assuming a frequency of 750 ∿.

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B. Line with Periodic Inductance Coils.

The following formula, due to G. A. Campbell, enables the attenuation on a non-uniform line to be determined :—

$$\cosh l_1 a_1 = \cosh l_1 a + \frac{Z_1}{2 Z_0} \sinh l_1 a \quad . \quad . \quad . \quad . \quad . \qquad (12)$$

where—

$a_1 =$ the required complex attenuation constant,
$l_1 =$ distance between inductance coils,
$Z_1 =$ impedance of a coil.

As shown by the curves (Fig. 9), strong attenuation takes place at a particular value of l_1, given by the expression—

$$\tfrac{1}{2} p l_1 \sqrt{L_1 C} = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

where L_1 is the total inductance per unit length assumed, uniformly distributed.

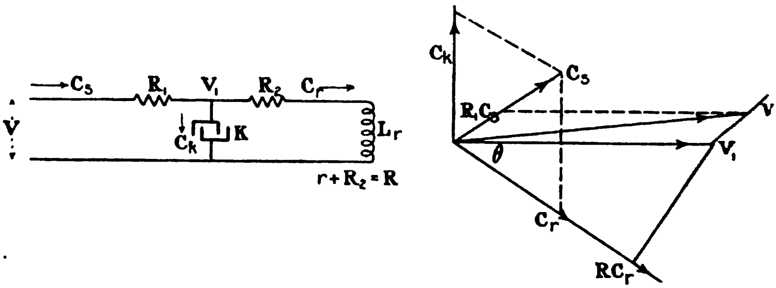

Fig. 19.

C. Relation of Sending and Receiving Currents on Short Lines.

In these cases the governing factor is the terminal apparatus, and perhaps the most evident explanation of the fact of the receiving current being larger than that at the sending end, is that the line capacity is supplying the idle current for the inductance of the receiver.

Assuming the total capacity lumped at the middle of the loop, we then have the ordinary vector diagram (see Fig. 19), from which the possibility of C_r exceeding C_s is manifest.

The condition for distributed capacity may be approximated to very closely in a telephone circuit by assuming condensers at 2- or 3-mile intervals. In formulæ (9) and (10) it is likewise fairly clear that for small values of $l\, a$, Z_s may be the larger impedance.

Opening or Short-circuiting Receiving End.

For $Z_r = 0$ it follows that $Z_s = Z_0 \tanh (l\, a)$, $\tanh (l\, a)$ being a quantity which tends towards 1 as a limiting value, but slightly exceeds 1 at a certain stage of the increase of $(l\, a)$.

Again, if $Z_r = \infty$, $Z_s = Z_0 \coth l\, a$, and it is therefore possible for the

impedance at the transmitting end to be greater when the far end is closed through a negligible resistance than when the far end is open-circuited.

D. Field's Theory of his Two-voltmeter Method.

Let V and C represent the instantaneous values of the current and E.M.F., and let K V and R C be voltages proportional to these, obtained by means of (*a*) a small step-down transformer, and (*b*) a series non-inductive resistance; let, further, D_1 and D_2 be the instantaneous values representing the sum and difference of the above voltages for the two positions of the reversing switch.

That is—

$$D_1 = RC + KV$$
$$D_2 = RC - KV.$$

We have then the relation at every instant—

$$\frac{D_1^2 - D_2^2}{4RK} = VC = \text{instantaneous watts.}$$

Representing the effective values of these quantities by $\bar{D}_1$, $\bar{D}_2$, $\bar{V}$, and $\bar{C}$—

$$\frac{\bar{D}_1^2 - \bar{D}_2^2}{4RK} = \bar{V}\bar{C}\phi$$

where ϕ is the power factor.

The resistance and inductance of the transformer secondary being of very slight importance, the only correction will be that due to the non-inductive resistance not being negligible in comparison with the galvanometer. This introduces the factor $\left(\frac{R+G}{G}\right)^2$ on the left-hand side of the above expression for the true watts.

E. Determination of Line Constants.

If Z_f = the observed vector impedance when far end of circuit is open,

Z_g = same when far end is short-circuited,

then—

$$Z_f = Z_0 \coth l\,a$$
$$Z_g = Z_0 \tanh l\,a$$
$$\therefore Z_0 = \sqrt{Z_f Z_g} \qquad (14)$$

and—

$$\tanh l\,a = \sqrt{\frac{Z_g}{Z_f}} \qquad (15)$$

$$a = \frac{1}{l}\tanh^{-1}\sqrt{\frac{Z_g}{Z_f}}$$

also—

$$\left.\begin{aligned} a Z_0 &= (R + j p L) \\ \frac{a}{Z_0} &= (S + j p C) \end{aligned}\right\} \qquad (16)$$

From equations (16), and knowing the value of $2\pi n$, the four constants R L, S, and C are obtained.

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F. Transmission Models.

A series of models illustrating in a topographic manner the variations of potential, current, and phase relations along a transmission line, have been constructed, see Fig. 20. Distances measured along the vertical spindle represent length of line, and the amplitudes at the different mileages are represented by the height of the radial

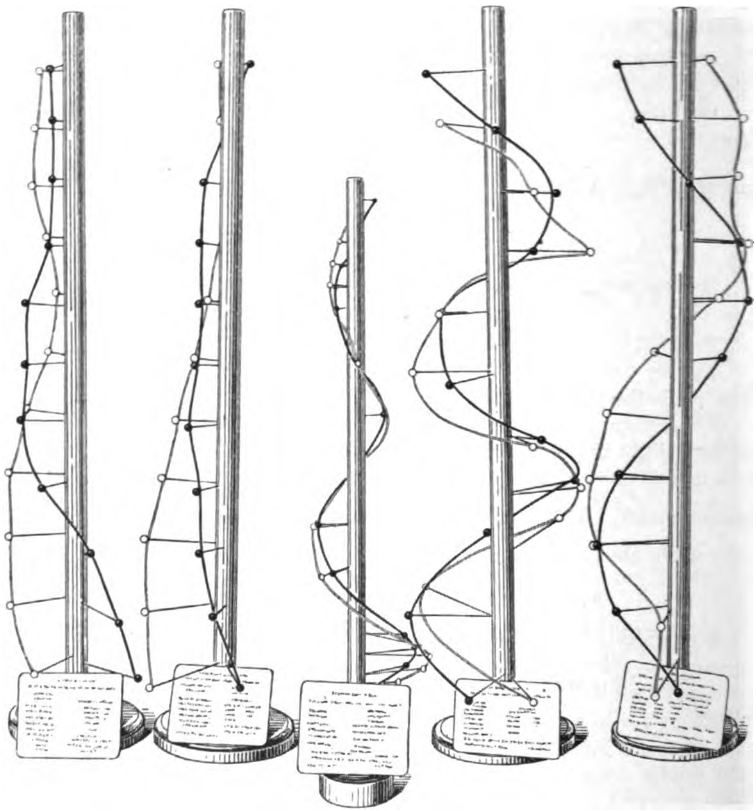

Fig. 20.

wires, whilst the phase lag in regard to the initial P.D. (which is the datum point), is shown by the rotation in the sense of a left-handed screw.

Figs. 21 and 22 also represent graphically the conditions of models 2 and 4. The line, however, is somewhat shorter, viz., 15 miles.

This method of mechanically demonstrating the progress of a wave, of course, naturally suggests itself if one calculates the potential and current values with their appropriate lag in phase down the line. This

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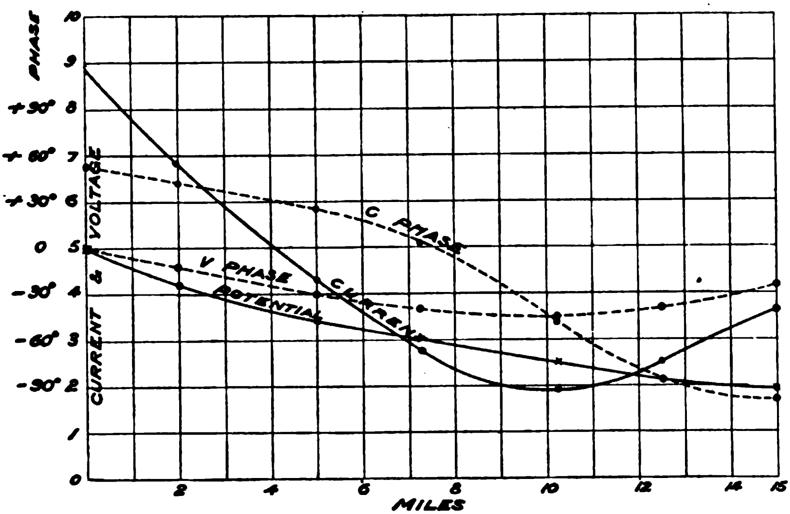
PHASE
CURRENT & VOLTAGE
+90° 8
+60° 7
+30° 6
0 5
-30° 4
-60° 3
-90° 2
C PHASE
V PHASE
CURRENT
POTENTIAL
MILES

FIG. 21.

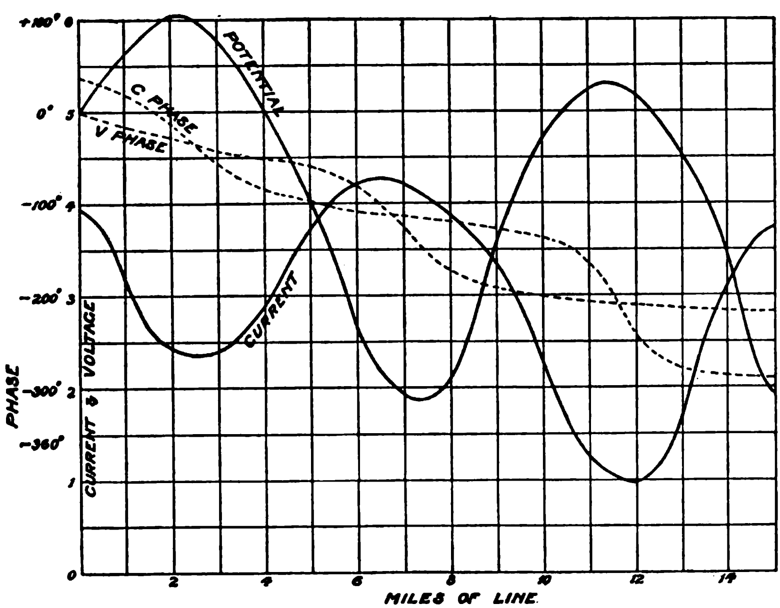
+180° 6
0° 5
-100° 4
-200° 3
-300° 2
-360°
PHASE
CURRENT & VOLTAGE
POTENTIAL
C PHASE
V PHASE
CURRENT
MILES OF LINE

FIG. 22.

Initial V.	Initial Current.	R.	C.	S.	L.	∿	Wave Length.	Remarks.
Model No. 1.—500-*mile* 400-*lb. trunk line. Terminal apparatus,* 230 *watts,* 0·085 *henry.*								
5 volts	7·8 milli-amps.	4·5 watts	0·0092 m.f.	10^{-6}	3·44 m.h.	800	222 miles	Phase difference between E. & V. about 10° average until terminal complicates matters. Attenuation regular for about 400 miles.
Model 2.—20-*mile* 20-*lb. cable. Terminal apparatus,* 145 *watts,* 0·1 *henry.*								
5 volts	8·9 milli-amps.	85	0·054 m.f.	Nil	Nil	800	58·6 miles	Phase difference about 45° to about half-way, and then phase gradually changes from lead to lag.
Model 3.—*Same as* 2, *but higher frequency.*								
5 volts	11·9 milli-amps.	85	0·054 m.f.	Nil	Nil	1,400	43·6 miles	Note much greater attenuation.
Model 4.—*Same as* 2, *but with load of* 0·085 *henry per mile.*								
5 volts	4·23 milli-amps.	85	0·054 m.f.	Nil	0·085 m.h.	800	18·5 miles	Much smaller attenuation than 2, but considerable periodic fluctuations.
Model 5.—*Same as* 4, *but higher frequency.*								
5 volts	4·43 milli-amps.	85	0·054 m.f.	Nil	0·085 m.h.	1,440	10·3 miles	

can be done either by the analytical formulæ for distributed capacity, etc., as was the case in this 500-mile trunk model, or by a simple graphical construction which assumes the line to be divided up into, say, 2- or 3-mile sections each containing a condenser, resistance, and inductance of the proper magnitude. The method of procedure, a form of which may be found in "Blakesley's Alternating Currents," chap. vi., is to assume a current or potential in the last section of the

line containing the instrument, and then work backwards to the beginning of the line.

Having thus reached the starting-point, the actual initial value of, say, the voltage is substituted for the constructional value, and the other points down the curve are reduced in the same proportion. The agreement between the analytical and graphical methods of describing these curves is very close provided the latter is not pushed too far in the matter of frequency or lumping capacity, etc. We believe that Dr. C. V. Drysdale, and possibly other people, have been working on these lines for demonstration purposes, and, therefore, no special originality is claimed.

There is also an interesting contribution to this subject from M. Blondel in *L'Eclairage Electrique*, commencing October 27, 1906.

Discussion.

Mr. A. Campbell: Before showing a simple experiment, I should like to make a few remarks on two points of interest in the paper. The first point I desire to refer to is the series of oscillograms of vowels and consonants given in the paper. I think a good deal of light would be thrown on such diagrams by a study of linguistic Phonetics, a science which is, I am sorry to say, almost absolutely neglected in this country. For instance, the break or "glide" between the *p* and *ee* or the *t* and the *ee* is quite interesting to the student of phonetics. In Southern English and German this glide is distinctly aspirated, but quite without aspiration in French. It is probable that the aspirated glide is of too high frequency and too small amplitude to show on the oscillograph. To get regular results in things like this, it is almost absolutely necessary to know a great deal about the actual varieties of vowels and consonants; for example, few people would notice that the *e* in "he" has not the same sound in Northern and in Southern English. On page 524 the authors remark that there appears to be a very considerable reduction in the effective insulation of paper cables at telephonic frequencies. I have no doubt that they used well-dried paper cables, *i.e.*, as dielectric, dry cellulose. Now, from experiments I made not long ago with cellulose, I found very clearly that in the air-dry condition, where there is a considerable amount of moisture present, the cellulose had a very much larger effective resistance for low than for high frequencies; and I notice that a similar result has been obtained by two French scientists in testing electrolytic resistances (dilute acid) with very high frequencies of several million $\sim$ per second. In the case of the well-dried paper cable I think the minute traces of associated moisture in the cellulose account for this change of effective resistance, for the most thorough drying always appears to leave a certain amount of moisture in the paper. Mr. Campbell.

The experiment which I proceed to show is to illustrate the action of an ordinary microphone transmitter. The alternating-current

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Mr. Campbell.

voltages generated by such a transmitter when in action can be measured by the arrangement shown in the accompanying figure (A). A solid-back microphone M is put in circuit with a battery B of 6 or 8 volts and the primary circuit of a transformer T, not an ordinary telephone transformer with 1 : 1 ratio, but a fair-sized spark-coil with a ratio of the order of 1 : 800. The secondary of this transformer is connected to a reflecting electrostatic voltmeter V_2 reading up to 10 volts. The deflections of V_2 are a sensitive indication of sounds received by the microphone. For loud sounds a 100-volt voltmeter may be used. If the nearly pure note of a stopped organ pipe be sounded near M and the pitch gradually raised, it is seen that for certain pitches the spot of light rushes off the scale. This indicates that the microphone gives strong resonance with certain frequencies. To make sure that the effect is entirely in the microphone and not a

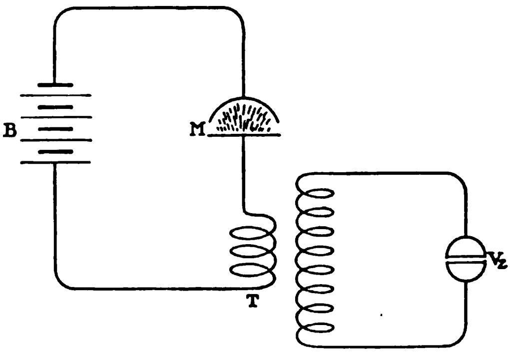

Fig. A.

property of the particular pipe used, I repeated the experiment with four pipes of different sizes (blown at constant pressure); the results shown in Fig. B leave no doubt that the resonance is in the microphone. In view of the fact that the transmitters and receivers ordinarily used have these strong resonance points at frequencies well within the working range, it seems surprising that speech can be transmitted so well.

Mr. Kingsbury.

Mr. J. E. Kingsbury: I take it as a privilege to have the opportunity of expressing the indebtedness of the Institution to Mr. Cohen and Mr. Shepherd for the paper which they have presented to us. In view of what Mr. Cohen has told us about the source of information for his paper, I think we ought also to express our indebtedness to the National Telephone Company for allowing him to place before us the record of work, which must have been costly and prolonged. If I assume that we are also indebted to our Vice-President, Mr. Gill, for the opportunity of having this paper, I am probably not very far wrong.

All these investigations have to deal with the transmission of

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Mr. Kingsbury.

speech; and the transmission of speech is obviously best considered by realising what speech itself is, and what the machines, if I may so term the instruments, and what the flexible connecting rods, if I may so term the lines, have to do. The telephone itself is due to Professor Bell's conception of impressing on the line an undulatory current, which should be the electrical equivalent of the aerial vibrations which permit speech to be transmitted from one portion of a room to another.

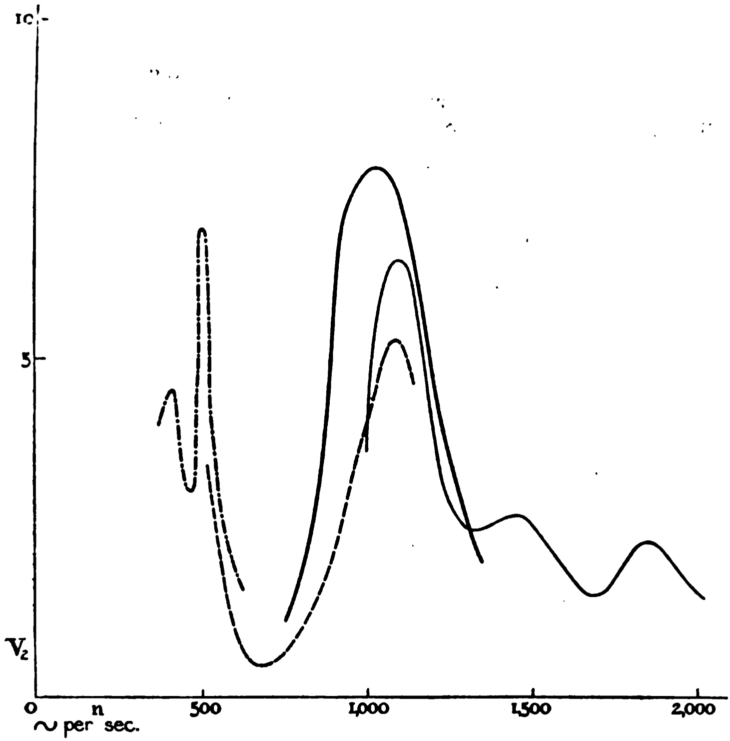

FIG. B.

If we bear in mind the origin of the telephone, I think it may help us to select what may seem to be the most promising line of research in order that improvements may follow. Speech is generally divided into two elements—consonants and vowels. It is assumed that a consonant is something definite and that a vowel is something definite. The authors have shown us that one kind of transmitter will give a more clearly marked definition of one of the consonants than another transmitter, and that is an important result in itself, provided the definition of the consonant is not obtained at the expense of some detriment to the transmission of the vowel. In my view of the transmission of speech

Mr. Kingsbury.

the vowel power is everything, and the consonant power is comparatively nothing. The consonant, in fact, as an element of sound, does not exist; it is merely a negative condition. The conventional name which we give a consonant can only be pronounced by the addition of a vowel. Commenting on Fig. 2, the authors say that the explosive portion of the consonants is quite separate and distinct from the vowel portion. I will not go so far as to say that we can take exception to this statement, but I do not think we can say that there is any point where a consonant ends and a vowel begins. Mr. Cohen has referred to the intervals of quiesence. My view is that that is not so much a boundary line between a consonant and a vowel as a breathing break between the start and finish of the vowel sound. The oscillograms which the authors have given us in their paper are really a very graphic proof of the accuracy of Von Meyer's analysis of speech sounds. Von Meyer says in his book, "The Organs of Speech," "The explosive *t* is necessarily followed by a breathing sound, which, when a vowel is the next sound intervenes as a hiatus." That hiatus is clearly observable in the authors' oscillograms. The consonant *t* on those oscillograms may be observed as something in the nature of a decrescendo sign which gives an outline to the wave. The wave is a vowel sound. The form which it assumes is the consonant, and if the consonant, instead of being placed at the beginning of the word be placed at the end, then the form will be a crescendo, or, in other words, the angle will be reversed. If we take the word "tea" we get a decrescendo; in the word "eat" we get the position reversed; but the whole of the time all we hear is the vowel; there is no sound in the consonant. Melville Bell, Helmholtz, and many other recent writers have analysed the various elements of speech, but an earlier writer has given a definition of a consonant sound, if I may use the term, which is noteworthy. Dr. Arnott, some eighty years ago, said in his "Elements of Physics or Natural Philosophy," "Consonants appear, then, not so much to be sounds, as distinguishable manners of beginning and ending sounds." On these lines it may be suggested that all the wave-marks on the oscillograms are really sounds, they are all vowels. The intervals and the form assumed by the waves are incidental to the formation of the consonant. The complexities of the vowel waves we have had fully placed before us. They are positive and they exist; the consonants are merely negative and do not in fact exist, except as intervals and modifications of the waves. From the point of view, therefore, of improvements in instruments, in lines and in loading coils, I think the line of investigation which offers the most promising field for results is to adopt the methods which shall best transmit the complexities of the vowels; and if they will do that, when we consider the enormous complexities of the harmonic forms of vowels, they will certainly do the comparatively simple work of the consonants. Still bearing in mind that the transmission will be best for electrical conditions which takes into consideration the originating effect, I would ask permission to be allowed to read one more

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extract. This is by John Hullah in his book on "The Cultivation of the Speaking Voice." He says, "If there be any maxim more frequently or more urgently commended to young readers and speakers than another, it is this: 'Take care of the consonants, the vowels will take care of themselves.' Like many other maxims, this contains not merely that 'mixture of a lie,' which Lord Bacon tells us 'doth ever add pleasure,' but so large a mixture of it as almost to neutralise whatever truth it may contain. Take care of the consonants by all means; they are the *bones* of speech; but take none the less care of the vowels, for they are its flesh and blood, without which consonants are but dry bones—void of heart as of life." My view in regard to improvements in speech transmission is that one can practically disregard consonant conditions. If we take care of the flesh and blood of our vowels, if we adapt our lines and instruments to them, so that they shall be enabled to transmit under the most favourable conditions the vowel sounds, the consonants can take care of themselves. Improvements in transmission, which we are all seeking, will undoubtedly result from such a paper as has been presented to-night. Mr. Kingsbury.

Major W. A. J. O'MEARA, C.M.G.: The authors have succeeded in compressing exceedingly important information into a very small space. Post Office officers have been very much interested in these problems of transmission since 1900, and the results of many of their investigations have already been published in the Presidential Address of Mr. Gavey. Unfortunately I have not been closely associated with the experiments which have been carried on at the Post Office during the past five years. It is nearly four years since I carried out some experiments between Liverpool and Warrington in conjunction with Mr. Tremain. There are many officers of the Post Office present to-night who have been associated with more recent experiments; they have up-to-date information, and I think it desirable that they should give their opinion at first hand. I have been very much interested in these oscillograph diagrams; and it may be a matter of interest to you to know that some three years ago, when we had one of those unfortunate differences with a corporation with which so many of you are acquainted, I found it very convenient to produce oscillograph diagrams to explain to the magistrate the difficulties which we have in connection with telephone transmission. On these occasions engineers are asked very many questions by people who do not understand the matter clearly, and I think a picture appeals more clearly to them than a long written description. I only wish that I could have had then something in the nature of the models which have been shown to us to-night; I think they, perhaps, would have been more useful still on the occasion referred to. My position was very similar to that of Sir Oliver Lodge's, who, when he was asked in a building close by here, "What happens when an electric wave meets a mountain?" suggested, "Ask me another." I feel that these oscillograph patterns will be of the same assistance to the designers of telephone instruments that indicator diagrams have been to those who are interested in the Major O'Meara.

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Major O'Meara.

design of prime movers. We have carried out a number of experiments on different apparatus, and we have known for some time that the telephone apparatus is not as efficient as we should like it to be. We happen to be in the unfortunate position of having to place something in a layman's residence which requires a very small amount of intelligence on his part to use. I daresay if we could have people who understood these matters a little more clearly we might produce more efficient apparatus. With regard to the information that has been compiled by means of these measurements, I may say that we have already put some of it into practical use. Schedule III. of a very important Agreement which has been entered into between the Post Office and the National Telephone Company was, I think, largely based on the result of these experiments. Of course we fully realise that these experiments have a large commercial value, and we certainly have every intention of making full use of this information.

Mr. Elton Young.

Mr. J. Elton Young: Having been engaged for the last five years in the Research Laboratory of the Submarine Cable Companies at Electra House, I have naturally been very much interested in this particular subject. I think it shows how much useful work can be done on artificial lines with the advantage of having no disturbance from neighbouring circuits.

I was glad to notice that the authors have adopted in the Appendix Dr. Kennelly's notation of the hyperbolic functions, which is so much easier than any of the older formulæ such as Heaviside's; also his use of the terms "sending-end impedance" and "receiving-end impedance." I should like to suggest that this notation of the impedances be sanctioned by this Institution, as it is becoming sanctioned by custom. The sending-end impedance $= \frac{\text{impressed volts}}{\text{impressed amperes}}$, and the receiving-end impedance $= \frac{\text{impressed volts}}{\text{received amperes}}$, each with its appropriate angle, and it is the latter quantity which we are dealing with in observing the attenuation. I had the pleasure of seeing some of the research work on the artificial lines of the National Telephone Company at their laboratory, and I think it is very satisfactory to find, as we have done in the submarine cable investigations, that the alternating-current formulæ are borne out by the experiments, and that in a simpler way than we had expected. For instance, the propagation of signals on submarine cables reduces practically to the attenuation of a single fundamental frequency, which works out in perfect agreement with the sine-waves assumed in the formulæ. In other words, in our problem there is only one important frequency to deal with, and no more. Similarly, the authors of this paper and others have discovered that the attenuation of a certain definite frequency of, say 800 (a kind of mean telephonic frequency), is a sort of measure of the efficiency of telephone circuits. Dr. Kennelly at the St. Louis Congress in 1904 said, "It is highly probable that the limiting length of circuit over which telephony is commercially possible is that which has a certain

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Mr. Elton Young.

definite receiving-end impedance at a certain standard sinusoidal frequency, whether the circuit be overhead or underground, mixed, loaded, or natural, and after variations in the sending-end impedance have been taken into account." Again, Mr. Gavey in his Inaugural Address in November, 1905, expressed a similar view, and laid it down that the limit of speech is fixed by attenuation or volume rather than by distortion or articulation. I venture to submit, however, that the foregoing rule has reference to circuits in which the leakage is negligible. Having made some actual experiments, I am fairly sure that sufficient attention has not yet been devoted to the application of systematic non-inductive leaks to telephone circuits. There is, I fancy, too much tendency to look askance at leakage, and to relegate the theory of the distortionless circuit to the limbo of abstractions. In the distortionless circuit, as is well known by students of theory, all the frequencies are received with equal attenuation, when the leakage has a particular value. This theoretical value, however, diminishes the volume too much. The proper leakage is a sort of compromise between the perfectly distortionless value and the perfectly insulated circuit. It is to the adoption of this critical artificial leakage value that I would ask the investigators to direct their attention. It is probably in the order of a few tens of thousands of ohms per mile, or less. It would be very interesting if any of those present could give us some data as to the improvement of speech due to leakage. If it is weather leakage, other things come into play, such as polarisation and disturbance effects. In that connection Mr. Campbell made the interesting remark that if we measure the leakage with an alternating current it seems to have a very low value. I would submit that that is not the leakage itself, but absorption—that it is not anything in the nature of discharging the line, which is the useful effect of leakage; it is a sort of electrolytic effect which is of a vicious nature. There are two published patents for this application of leakages, namely, Sir Oliver Lodge's and Jacques', the former for cables and the latter for both cables and overhead lines. So far as I am aware there has not been very much done in that direction, but I feel sure leakage will help for telephoning over the submarine cable. Of course on overhead lines it is possible to insert Pupin coils and to dispense with leakage there. I should like to point out that if we make our measurements with a pure sine-wave we are not dealing with distortion at all, the wave being only of one frequency, and the term therefore has no meaning. The best plan is to plot the curve of the rise of attenuation with frequency, as the authors have done in some instances. This takes into account everything that we require to complete our information as to the circuit. Another plan for measuring distortion is the angle of the sending-end impedance, which is usually something like 45° on cables. If that is reduced to something like zero we should have a distortionless circuit. The outcome of our experiments in this direction in the Research Laboratory of Electra House was that the barretter methods were not very useful for the low frequencies we had

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Mr. Elton Young.

to deal with. We found that, in dealing with such low frequencies, we had to insert very large inductance coils in the arms of the bridge in order to stop the alternating current from getting into the bridge arms. This eventually led up to a new method, which my colleague, Mr. Davies, has evolved, which I hope will be the subject of a communication from him later on. I should like to ask any of those present whether they have tried the effect of a magnetic shunt on the receiving telephone.

Mr. Gavey.

Mr. J. Gavey, C.B.: I should like to join my thanks to those of the previous speakers for the paper that has been read before us to-night, a paper that has involved a vast amount of laborious work, and which will tend in the future to the improvement of the art. It contains so many points of interest that I am afraid it is only possible to refer to a very few. In the first place, I may say that I was very interested in comparing the oscillograms which have been reproduced in this paper with those I showed in 1905. At first sight they did not seem to be quite in agreement, but I think on closer examination it will be found that they are really of the same type. I should imagine that the oscillograms taken by the authors of the paper were taken on a more rapidly moving plate than those that were taken by the Post Office; hence the detail comes out more distinctly in these last oscillograms than in the first ones, but, on the other hand, there is a general resemblance between the two. In reference also to the question of consonants and vowels, I think in some of the oscillograms that I gave in 1905 it was only supposed that single letters were sounded. There was necessarily a combination of vowels and consonants, such as when the letters *p*, *m*, or *l* were used. Referring back to these earlier oscillograms, I do not observe that interval between the vowels and consonants that was shown to-night, but that may also be a question of the speed of the falling plate. I did not gather from the authors what frequency they would adopt in designing telephone lines, whether they would be satisfied with 750 to 800, or whether they thought it was necessary to provide for a frequency of 1,100 to 1,600. On this point a question, I think, of very great interest arises. I think we may deal with the question of lines, either overhead or underground, on a mathematical basis, and so far such improvements as have been made in the transmission of waves over long lines have all been based on mathematics. I am not quite certain that we can adopt a wholly similar method in the endeavour to improve the telephone, either as a transmitter or a receiver. We must bear in mind that our senses, whether of sight or of hearing, imply something more than a mathematical, optical, or aural instrument. Take the eye, for instance; when we see a distant object, mathematics will tell us that that object subtends a certain angle; but if we compare the result of a photograph of a distant ship with the effect impressed on our mind by a visual examination of that ship the two results are vastly different. At a distance of half a mile or a mile a large liner on a photographic plate would appear as a small vessel, and we can form from the examination of the photo-

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graph no idea of the size of the ship. On looking at the ship at a great distance with the eye, there is some unexplained sense that comes into play that enables one to judge, with more or less accuracy, what the size of that ship is. Again, the same thing applies to the hearing. If the ear were simply a musical instrument, the result would depend entirely on the oscillations and on the harmonics, and without a more or less accurate reproduction of the harmonics we should not get an actual reproduction of the sounds which we were listening to. But the ear is very differently constituted. We listen to speakers of all kinds, those with clear, distinct voices in which all the harmonics are apparent; but there are speakers, on the other hand, who speak as though they have their mouths full of some plastic substance, and no harmonics are perceptible. Yet we get the articulation in both cases, and we understand perfectly what is said. I think that the telephone gives us somewhat the same results when we are talking on long-distance lines. I think there is no doubt that on extreme lengths even more of the harmonics are cut off than has been represented in some of the diagrams and curves given here. Yet when we get to the very extreme lengths of line over which it is possible to get articulation, the skilled telephone user does not miss articulation; he can hear perfectly what is said as long as there is sufficient volume. I only mention that because I think that, useful as the mathematics of the telephone may be, we want to master certain other factors before we can hope very largely to improve the telephone. There is also another difficulty we must bear in mind. The telephone has to meet extremes of conditions which I do not think any other piece of apparatus in use in the applied arts has to. A telephone must speak clearly from one room to another at one moment, and the next moment with that same instrument one must be able to speak with equal facility over a line of a thousand miles in length. Those are extreme conditions which, as I say, I do not think any other piece of apparatus has to meet. On page 511 the authors state that speech was impossible with irregular loading at a space four miles apart. I understand that they could hold no speech whatever over those sixteen or twenty miles of line when the balancing inductance was spaced at distances of four miles. That is really extremely interesting, because, on the other hand, with the unloaded line, they could get speech up to a range of fifty miles. We all know that it is impossible to neutralise the effect of capacity by lumping inductances at long distances, but I should hardly have expected that this lumping of inductance at a space of four miles would have had such an effect. It is rather interesting, perhaps, to state that as a result of a number of experiments the Post Office made some six years ago in loading the underground trunk lines which were then being laid, we came to the conclusion that, if the inductances were spaced at distances of about two miles, we got really very excellent results; and I think it is very gratifying to find that the mathematical results which have been obtained by the authors give about the same figure. In the loading of lines there are two factors to take into consideration. The closer the spacing the Mr. Gavey.

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Mr. Gavey. more distortionless the wave; on the other hand, one may space so closely that it would pay better to use a larger conductor and to do away with the loading. I think that would apply, perhaps, more exclusively to overhead lines than to underground lines. It is a very nice point in reference to overhead lines where loading is advantageous, and where, on the other hand, it would be an advantage from the financial point of view rather to increase the gauge of the wire.

Mr. Hill. Mr. J. G. HILL: I should like to refer first to the tables given on page 508 of the paper. It would be useful if we had a little more information as to the precise meaning of the columns "Percentage Received." I take it they are valuable in so far as they represent the distortion of the impressed wave, that is to say, of the voice impressed by the speaker. It appears from Fig. 3 that there is an amount of distortion introduced by the diaphragm of the transmitter, as well as the cable, and this was also made very evident by Mr. Campbell's experiment, which showed that we have resonance in the transmitter, so that really the electrical waves impressed upon the circuit are practically not those of the speaker's voice, but that voice distorted by the diaphragm, and it is quite conceivable that any subsequent distortion might in some cases be such as practically to bring back the voice to what it should have been originally. I should like to ask the authors in this connection whether more than one transmitter and more than one length of line were tried, because if so, that might throw light on some of the distortion. It would also appear from an examination of Fig. 7 that if the method of Fourier's analysis had been applied to this curve it must have been a very difficult matter, because from an inspection of the curve it would appear that the line constituting it is in thickness about half the length of the ordinate. Referring to the subject of the highest important frequency in telephone waves, which is dealt with on pages 510 and 512, I think the average engineer would be glad to know exactly why it was concluded that harmonics above 1,600 may be dispensed with. Of course I quite understand that it would be possible to determine the velocity of propagation, and having done this to arbitrarily determine the wave length. It is generally assumed that we must have a distribution which is denoted by x loading coils per wave length, say 3, and from those we can calculate what the wave length must be. That was the method adopted by Dr. Hammond Hayes and explained by him at the St. Louis Congress. He estimated from his experiments that the highest important frequency was just over 2,000. The result here, allowing for differences in observation in a very complex and abstruse subject, is not very greatly dissimilar to that given by the authors of the paper. I would call attention to page 512, where it is stated that "Pupin and others used 750 to 800 frequencies for many transmission calculations. It is important to know that this represents a fair average frequency, as damping constants calculated with this value can be obtained experimentally when using actual speech waves." It seems to me if we take 1,500 as the highest important frequency we must really assume

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something less than 750 as a mean, because it is one of the features of harmonics that successive harmonics become progressively less in intensity, so that the resultant as regards volume must approximate more to the lower frequency. If we adopt the higher frequency of 2,000, then it was pointed out by Dr. Hayes at the St. Louis Conference that we should have very nearly 800 frequency as a mean, and this is generally admitted to be borne out by actual experimental speech results. Mr. Hill.

Referring next to page 519, we have there a number of values calculated and observed. In connection with this I also wish to refer to page 524. We are told in a paragraph immediately under the Table given on that page that "The constants *l* and *s* in the case of the 20-lb. cable are possibly doubtful, owing to the phase-measuring difficulty referred to, but there is good reason to believe that there is a very considerable reduction in the effective insulation of paper cables to telephonic frequencies." I was wondering whether that had been taken into account in calculating these percentages of error. The point appears to me to be important in view of observations made by Continental observers. In the *Electrician*, dated November 2, 1906, in an article by Béla Gàti, measurements made by himself and Dr. Breisig are given, and it appeared that the calculation of the damping constant, showed that he found an error of 20 per cent. would exist if the increased leakage were neglected as regards cables. Has this been taken into account in these tests, and if so, can the authors tell us exactly what it amounted to?

Referring to Figs. 15 and 16, the curves are different from those which would be obtained if attenuation were calculated on a line without terminal impedances. The question I desire to ask is, How do these terminal impedances affect the reliability of the numerous voice tests that have been made in connection with this subject, in view of the fact that in those tests impedances were not taken into account? (I have no doubt Mr. Cohen will remember the tests I refer to.) It appears to me that, seeing that in the method of measurement by voice tests we are in the habit of using the same telephone on any two circuits which are equal as regards attenuation, taking it from one to the other, we thereby introduce exactly the same amount of disturbance on the one as the other, and that practically the method of calculation (neglecting reflection when the lines are unloaded) would hold good whether we took the terminal impedances into account or not.

I think the paper affords us very valuable information, particularly from the laboratory point of view, on the questions of improvements in articulation and the possibilities of improvement in design; but it seems to me that, notwithstanding this, we must still rely upon the voice test, that is, the comparative test. This, the ordinary commercial test, is the mainstay of telephonic transmission, because by that test we are able to reproduce all the conditions of the problem which we require to solve in ordinary commercial practice.

If I have not alluded to the many valuable and important features

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Mr. Hill. of the paper in detail, it is only because time does not permit, and not in any sense because I am not fully aware of them.

The meeting adjourned at 9.30 p.m.

DISCUSSION AT MEETING OF MAY 16TH.

Mr. Duddell. Mr. W. DUDDELL: I have much pleasure in opening the discussion to-night, as I have made a number of telephonic measurements. When I see the great amount of work that the authors have brought before us, I realise the time and trouble they have spent preparing this paper, and I feel that the authors have been very properly honoured by the Institution in awarding them a premium for their very valuable paper.

About a year ago I was called upon, at very short notice, to give a discourse at the Royal Institution, and I chose as my subject "How to Improve Telephony." In that discourse I described a certain number of instruments which I thought might be used for telephonic measurements. It is a great pleasure to me to see that the authors have been using very similar methods to those I proposed in that lecture. I can only hope that my lecture may have stimulated them to press on in their research; I do not think it started them on it, because they were at work on the subject before.

The first point I wish to refer to is the question of the vowel sounds. Figs. C to F are records I have obtained when producing sustained vowel sounds before a S.B. transmitter for comparison with those in the paper.

For instance, Fig. C represents the *a* in a word like "ma," for comparison with the second curve in Fig. I. It consists of the repetition of a series of oscillations which die away, and the pitch is determined by the number of the groups of oscillations per second. It seems as if a series of puffs were produced by one cavity in the body which set up damped oscillations of a higher frequency in a second cavity.

Fig. D is the *e* sound in a word like "me." Its characteristic with my voice is the small oscillations on the curve. The curve looks rather like a zigzag alternating-current machine curve, with these little characteristic oscillations superposed, and whenever I have an *e* occurring in the middle of the word, I get these little oscillations by which I am able to recognise it (see Fig. H).

The simplest sound I am able to make is the *oo* sound in a word like "coo." Fig. E is almost a sine wave. The slightest alteration of the cavity of the mouth alters this sound into the form Fig. F by the superposition of what appears to be the second harmonic or octave. The notch may occur, as far as my experience goes, at any point of the curve, although the sound seems just the same to me.

The authors have also dealt with the consonants. I look upon the consonant as the starting of a vowel sound. Fig. G, for example, is the explosive *b* at the beginning of "ba," which shows the puff of air and the formation of the oscillations of the *a* sound.

One of the most difficult letters in telephony is the hissing of the *s*, because the frequency is so high. I have made a great many experi-

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ments for the purpose of trying to get a good record of the hiss. You s s s loudly, but it makes hardly any effect on the telephone diaphragm. The frequency of the oscillations is between 1,500 to 2,000 per second. Mr. Duddell.

"*Ma*"

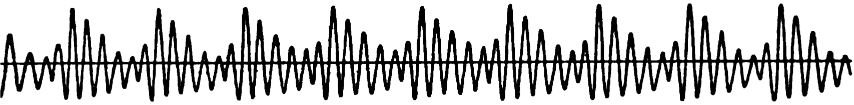


FIG. C.

"*Me*"

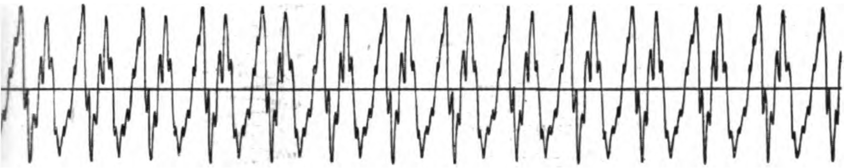


FIG. D.

"*Coo*"

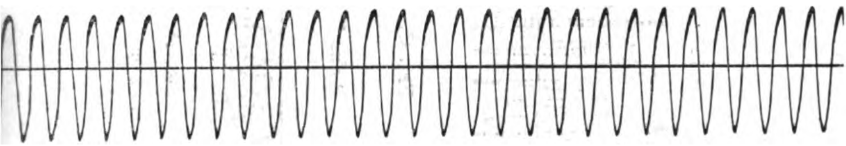


FIG. E.

"*Coo*"

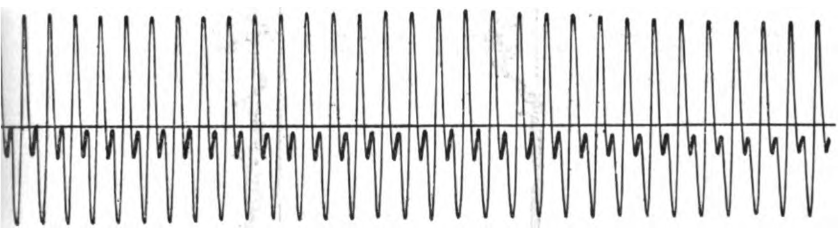
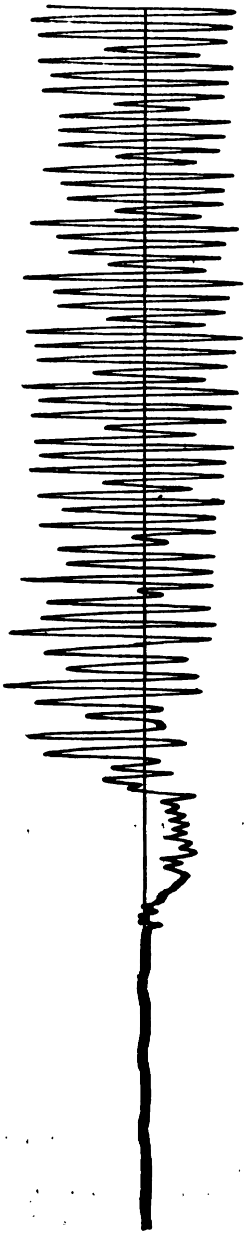


FIG. F.

Scale of time 1 mm. = 0·00036 sec.

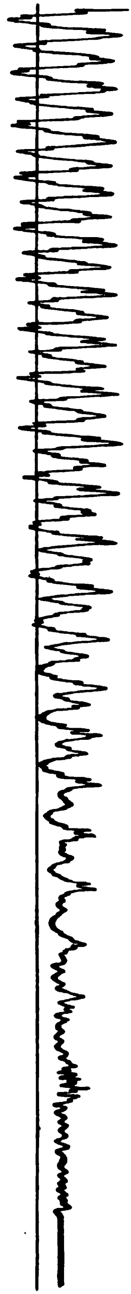
Fig. H is the *k* sound in "kee," which has rather a curious beginning, and which shows the formation of my *e* very well on the right-hand side. I hope that one may in time be able to learn this alphabet, so as to be able to read the oscillograph record of a telephone conversation.

Mr. Duddell.



" Ba '

FIG. G.



" Kee "

FIG. H.

Scale of time 1 mm. = 0·0004 sec.

Mr. Duddell.

I have been making very long records, over 100 ft. in length, for a special purpose, because they may have an interesting, practical use in telephonics. These records correspond exactly to the other oscillograph records with one difference, namely, in making the record one half lengthwise has been filled in black, so that the border-line between the clear and the opaque parts has the exact shape of the oscillograph curve. This filling in is done automatically when making the record. If by any method I draw the record past a slit through which a beam of light is passing, then, as part of the film is black and part of it is transparent, the amount of light passing through the slit will depend upon the relative amount of black and clear film, so that we shall have the light varying according to the shape of the recorded curve. If this light is caused to fall on a selenium cell, it is possible to reproduce the film again as actual sounds. The effect is, at present, too faint to show at the meeting. The arrangement forms an optical phonograph.

Mr. Gavey, in his presidential address, showed us some interesting curves that he had obtained. I should like, if it is in order, to ask if we could have put on record the exact pronunciation of the vowels and consonants in Mr. Gavey's address.

I should like to ask the authors whether one or two of their curves are not reversed. The *a* in Fig. 1 has the appearance of being reversed.*

The next point I wish to mention is the question of power measurement. I had, in connection with some measurements on the resistance of the electric arc, to use the 3-voltmeter method, and I found that it was so successful for measuring power even at frequencies up to 120,000 $\sim$ per second, that I think it is a better method than the one used by the authors.

Another point the authors refer to is the question of getting a high-frequency sine-wave alternator. Some time ago I had the pleasure to lend Mr. Cohen a high-frequency alternator, which did not give a sine wave; it is not the one referred to in the paper. Since then I have been able to modify the machine, so as to get at 500 or 600 frequency, a really good sine wave, and an output from 10 to 20 watts. The alternator the authors describe has, I gather, an output of only 1 or 2 watts. I see no difficulty in getting a good sine-wave alternator to give sufficient power for all ordinary measurements. I have in the past made an alternator for 120,000 frequency very much similar in principle to the one the authors are using; it gave the same type of wave-form as they have shown, but not quite so good, because the air-gap was not so long.

This brings me to one of the most important points in the paper, namely, the wave filter. I think that the instrument is one of the most important things the authors have described.† It will enable us to use a bad wave-form alternator at a high frequency, and to sort out

* The error referred to has since been corrected.

† I regret that in the discussion at the meeting I overlooked the fact that this device is due to Mr. Campbell.—W. D.

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Mr. Duddell. the upper harmonics and get a good wave from it for experimental purposes. I trust the method will have great application.

The next point to which I wish to refer is the measuring of small alternating currents. I have in the past devoted considerable time to considering methods for measuring small alternating currents. In 1904 I read a paper before the Physical Society, in which I described the thermo-galvanometer to which the authors have referred. Subsequently I was asked by the French Post and Telegraph Department to give them an official lecture on the measurement of small alternating currents. At that date I went into the various methods, the bolometers, the thermo-galvanometer, the expansion of wire, and thermo-couple methods of measuring small alternating currents, and I published a number of comparative results. I compared platinum iron and carbon (lamps) as barretters, and I wish now to draw attention to the sensibility of the iron wire barretter. Iron wire has the peculiar property, that over a certain temperature range its resistance rises very rapidly, and it makes an extremely sensitive instrument if the measuring current through it is adjusted to near the critical value. In some comparisons I made between very fine platinum wire (Wollaston wire) sealed in a vacuum; an ordinary iron wire, about 0·8 of a mil. in diameter, sealed in vacuum; and two telephone signal lamps, kindly supplied by Mr. Kingsbury—I came to the following conclusion as to the relative sensibilities: With the platinum wire I was able to obtain a standard deflection of 250 millimetres, at a metre, for 0·187 milliampere. With the iron wire I could obtain the same deflection with 0·845 of a milliampere. With a 12-volt lamp it required 2·50 milliamperes and the 4-volt lamp 2·85 milliamperes. All these results were taken with the optimum bridge current. The iron wire is very stable —it is more sensitive than the lamps I have used—and it is very much more convenient to use than any form of platinum wire barretter that I have yet found, because the fusing current is so very much higher. With reference to measuring these small alternating currents, I have been trying to see if it is not possible to make a pivoted instrument which could be used by telephone engineers for testing. The first model of a sensitive pivoted thermo-galvanometer, intended for measuring small alternating currents, is on the table. The instrument has a resistance of about 69 ohms, and actually takes about 16 milliamperes to deflect right across the scale. I anticipate that such an instrument may be of great use in testing, because it is easily portable, and saves any question of galvanometer spots or complicated adjustments. I should like to ask the authors if they will tell us in their reply the resistance of the lamps they used in their tests for the bolometers, and what current they took to give 250 millimetres at a metre, 1 in 4 deflection, so that we may be able to compare the power taken by their lamps, in their method, with the power taken by the lamps I and other experimenters have been using. It is very important to have a common basis of comparison for the sensibility of all these instruments.

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Mr. J. E. TAYLOR: There are not many points I wish to refer to, but the first that occurs to me is the question of distortion. The authors on page 510 refer to the "instinctive quality of the human ear for recognising what must in reality be the merest phantoms of speech vibrations"; and they point out that volume is the prime necessity, and articulation is, comparatively speaking, a secondary point. I think when one goes a little further into the question there may be a tendency on the part of telephone experts to ignore the question of articulation. Mr. Duddell and others have shown us that a very great deal of distortion is introduced by the diaphragm of the microphone and the transmitter as a whole. The first distortion which is introduced is that of the speaker himself. No two speakers pronounce the same vowels in exactly the same form; there are considerable differences. Another very considerable distortion takes place in the receiving instrument. Apart from the line there is, I think, a great probability, or possibility, of much of the distortion that exists being removed. If the apparatus be improved in this particular, the line distortion will no longer be negligible, and I think from that point of view it is not wise for telephone engineers to ignore altogether the distortion produced by the line. I think that point will be brought forcibly home to you when I point out that the formula for the attenuation, upon which a good deal of stress is placed, ignores altogether the effects of distortion. I have had occasion in one or two instances to notice how much may depend upon clearness of articulation. In such cases, for instance, as the wireless telephone depending upon the conduction method, an example of which I installed for the Post Office between the Skerries Lighthouse and the Island of Anglesea, the very small volume of speech which is transmitted renders it necessary to pay very great attention to the character of the transmitter, and reduce instrument distortion to a minimum, in order that intelligible speech may be conveyed. I understand from Professor Fessenden's recent writings concerning wireless telephony by means of high-frequency oscillations that the clearness of speech which it is possible to get from the special transmitters used in his system is in advance of anything attainable over even the shortest lines, mainly as a result of minimising instrument distortion and complete absence of line distortion. Distortion is a very difficult thing to measure, but there is one method which suggests itself to me which might be applied. The main cause of distortion is the different amount of attenuation produced upon different frequencies of transmitted impulses. If we take the ratio of the attenuations of, say, the lowest important frequency in speech as compared with the highest important frequency of speech, it should, I think, give us a fair measure of the actual line distortion. Mr. Taylor.

Another point to which I should like to make brief reference is the authors' method of determining the highest important frequency by the spacing of loading coils. It is extremely interesting, and the curves are interesting, because they show such an abrupt change with a comparatively small variation in the distance apart of the loading coils. I

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Mr. Taylor. think, apart from the attenuation formula or the mathematical explanation of the effect, the reason is somewhat obvious when we come to consider that we are really dealing with a propagation from one end of the line to the other, so that when an impulse starts along a long telephone circuit the shape and strength of the impulse is not at all determined by what it is going to meet when it gets to another part of the line. That is to say, the effects taking place within a certain section or length of the circuit are independent of the conditions in the remainder of the circuit; so that the effect of the spacing of the loading coils is largely determined by the wave length of the impulses. I think the same view of the case applies to the effect of opening and closing the distant end of a circuit so far as the effect or absence of effect on the transmitter impulses is concerned. With regard to the type of measuring instrument which the authors prefer to use, I may say I have a very kind regard both for the thermo-galvanometer as a measuring instrument and the microphone reaction transmitter or generator as a source of alternating current for measurement. I think they each have some advantages which perhaps the type of instruments used by the authors have not, although, of course, I admit they have some disadvantages. In the first place, I understand the authors' reason for not using the thermo-galvanometer is that it is too sensitive for them. I have not found that to be a very good reason for abandoning the use of an instrument in making laboratory tests, because there is usually some way of getting round the high sensibility. There are methods equivalent to that of shunting highly sensitive direct-current galvanometers applicable in the case of a thermo-galvanometer. Then, as regards the microphone reaction transmitter, the authors complain it is unsteady and does not give reliable sine-waves by any means. I have not actually used these reaction transmitters for frequencies higher than 400, although I have seen them so used, but for a frequency of 400 a microphone reaction transmitter can be built which will give something very closely approximating to a sine-curve, and for experimental purposes a pure sine-curve can be sifted out of it by using twin circuits which are lightly coupled to one another so as to avoid the reaction of the secondary circuit upon the primary, and thus allow resonance to have full play, thereby clarifying the wave. In my experience steady resonance effects cannot be obtained with alternators, and this is a drawback. The authors have referred to what they term the wave filter for purifying the wave from a high-frequency alternator. I think a few details of what this wave filter consists of would be very interesting to many of us who have not had the advantage of having seen the instrument or any description of it.

Mr. Laws Webb. Mr. H. Laws Webb: I am afraid I cannot carry on the debate at the high level of scientific interest at which it was started to-night. It is rather a relapse to come down from the scientific beauties shown and explained by Mr. Duddell to dry engineering details. There are two points mentioned by Mr. Cohen and Mr. Shepherd, the relation between which seems to me to have escaped attention in the discussion.

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Mr. Laws Webb.

An introductory remark refers to "the realisation of the large expenditure involved in line construction and the consequent possibilities for economies"; and there is a reference later on to "the instinctive quality of the human ear for recognising what must in reality be the merest phantoms of speech vibrations." There is a distinct relation between those two points. It seems to me that these investigations show that our early ideas as to the requirements of telephonic transmission were pitched too high. We originally thought that we must reproduce every harmonic and every overtone of speech waves. That meant establishing very high standards of telephone transmission, and that in turn led to the use of very expensive line plant. In the early days nothing less than 20 lbs. copper was considered suitable for underground cables for local work, and the weight of copper for overhead work gradually went up with distances from 100 lbs. a mile to 425 lbs. a mile for the New York-Chicago line, and in this country at a bound to 800 lbs. of copper for the London-Glasgow line. Line construction on that scale involves very large expenditure. We often see in the papers ignorant and superficial criticism of telephone rates, but I think few people realise that the speaker by telephone from London to Glasgow has the exclusive use for the time being of a circuit containing 300 tons of copper, worth for copper alone to-day about £30,000, and the total capital cost of the circuit is considerably higher than that. I think if the Postmaster-General were to figure out how many penny letters give up their profit to pay for the loss on a telephone conversation between London and Glasgow he would rather get cold shivers.

These investigations, in their engineering application, go to prove that the high standards originally fixed were unnecessary, that it is not necessary to reproduce photographically, so to speak, every vibration of speech waves. The investigations of the authors show that, to a certain extent, the waves can be flattened out, suppressed, kinked and otherwise distorted, and still give good commercial speech. That is not really so very extraordinary, because the same thing happens in ordinary air transmission. Ordinary speech is frequently greatly distorted by different people in different parts of the same country. For instance, if we compare English as it is spoken in London and as it is spoken, say, in Glasgow or in Somersetshire, we find considerable varieties of distortion in those different parts of the country. I should like to say here a word for the consonant. It seems to me that the consonant was very unjustly depreciated the other night. Mr. Kingsbury, I think, said that the consonant merely served to begin and end a vowel sound and was relatively unimportant—that if we take care of the vowels the consonants will take care of themselves. It seems to me that that is something like saying that the only important part of a man's dress is his waistcoat—that the coat and trousers merely serve to begin and end the costume. I think it is a matter of common observation that if one varies the coat and trousers and retains the same waistcoat one can get very startling effects! Certainly the same thing occurs in English speech with a great many words of one syllable. I

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Mr. Laws Webb.

daresay the imagination of the audience is equal to picturing the startling change that may be made in words of one syllable by simply changing the consonants. I am afraid it would lead to making many embarrassing remarks! The bearing of all that is that it is an incontestable fact that speech is largely distorted in the ordinary way without telephonic transmission, and that the instinctive capacity of the ear for recognising sounds and interpreting them to the brain, even though they are distorted, is fully equal in most cases to the occasion. These investigations show that the same thing happens in telephonic transmission, and that the instinctive quality of the ear for recognising even phantoms of speech waves and interpreting them correctly is a valuable commercial asset to a telephone administration. The bearing on the engineering of a telephone system is this, that the line plant is by far the greater proportion of the whole capital cost of a telephone system. In most telephone literature the exchange apparatus and the instruments play the important part, because those are the things people see most, and they work and move and so on; but the inert and comparatively unseen line plant is where the money goes, and is by far the most important part of the whole concern from the financial point of view. One may go to-day to twelve or twenty different manufacturers and obtain a complete common battery exchange which will work perfectly well as long as it is properly taken care of. It is wise to specify for the individual requirements, but one does not need, strictly speaking, any engineering for buying an exchange equipment. But there are very few telephone engineers who can lay out the line system for a large telephone exchange so as to combine economy with efficiency. One could not go to a single cable manufacturer and entrust him with that work. That is no aspersion on the manufacturer, because it is not his business. His business is to turn out the cables, but not to combine them into a system. I remember a good many years ago astonishing a number of telephone people by analysing the capital cost of a large telephone system and showing them that 75 per cent. of the total capital cost was in line plant. That was a company which owned a considerable amount of suburban trunk lines, so that that was a little high; but even to-day it is very little below 70 per cent. for the ordinary local telephone system—70 per cent. of the capital cost is in line plant. I checked only a day or two ago some very elaborate estimates for a telephone system for Chicago, and the line plant ranged from 61·5 per cent. to 67·5 per cent. of the whole cost, and in the case of the lower proportion a very large amount was allowed for buildings. Taking a mean of 65 per cent. for the proportion of capital cost invested in line plant, it will be found that in the National Telephone Company's plant and in the Post Office local systems there is a total of £10,100,000 invested in line plant to-day; and the Post Office trunk system, which is practically all line plant, has cost another £2,900,000, making £13,000,000 invested to-day in Great Britain in telephone line plant. That not only means copper

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and cables, it means priceless space under the streets of our great cities, and space is becoming priceless even along the country roads. The engineering bearing of these investigations, which show that we can use less copper and so use less space, the capacity of the 3-in. duct having been increased, partly by reason of these investigations, from 50 to 600 pairs of wires—the engineering and the economic bearing of the question is so great that I think that if barretters and oscillographs had to be made of solid gold, and if the investigators had to be paid the salaries of Cabinet Ministers, it would still be true economy to carry on such investigations. Mr. Laws Webb.

Mr. S. EVERSHED: I had the honour of being admitted to the Institution about twenty years ago, and I have been waiting for this paper ever since. I am happy to say I have not waited in vain. I am not going over the whole history of the telephone in this country, but I want to remind members that the telephone was invented in 1876, nearly thirty-one years ago. To-day, as an instrument, it is precisely what it was when it was invented, neither better nor worse. I remember, within a few weeks of the arrival of the first telephone in this country, I set to work, by the aid of two wooden baking-powder boxes, a couple of pieces of sheet tin which I cut out with nail scissors, to make diaphragms, two coils and two rough permanent magnets, to make two Bell telephones. I remember that, when I got some one with sufficient confidence to stand at the other end of the line, I felt rather like a fool when I spoke to my telephone and said, "Do you hear what I say?" The first words I heard, perfectly articulated, were, "Yes, I hear you quite plainly." I do not think I ever heard a telephone speak with clearer articulation than that baking-powder box telephone! All one wants is a diaphragm, a magnet, and a coil, and that is just what we have to-day. The question of articulation is a very important one, and in spite of what the last speaker said about articulation not being so essential as other qualities, speaking as a telephone user, I cannot help thinking that want of articulation is one of the worst faults that the telephone has to-day from a commercial point of view. But the problem of the line is apparently the crux of the whole matter at present; and although I have referred to the telephone as an instrument, it does not appear to me that the time has yet come for tackling its improvement. What is this problem of the line? What we are really dealing with is the simultaneous transmission of a number of alternating currents of different frequencies through a line. We can send them in at one end all right, but how do they come out at the other? The different frequencies arrive with the wrong amplitudes, the wrong shapes, and the wrong phases. The phase relations are altered as well as the amplitudes, and the whole thing is what is called distorted. At present Messrs. Cohen and Shepherd and other workers are doing their very best to find out what is really wanted at the other end of the line. How much of what is put in at one end do we want at the other? We certainly want the amplitudes to be large enough, but that is no use unless the different waves preserve their Mr. Evershed.

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Mr. Evershed.

relative amplitudes. But do we want the phase relationship to be correct? Do we want it to be the same as it was when the train of waves started? That is a question which really turns far more on physiology and psychology than on electricity. A chord on an orchestra does not depend for its effect, or its power to please the ear, in any way on the phase relation of the different frequencies set up by the different instruments; they all start quite haphazard. If Mr. Duddell could take a number of oscillograms showing the waves of all the instruments in the Queen's Hall orchestra, we should find that they all started quite at random, and that there were no two waves in phase; yet although one probably never hears a chord twice alike as far as its phase relations go, the effect on the brain is the same. The ear does not detect the difference. That is a strong argument in favour of the phase relationship not being necessary to clear articulation and the understanding of speech. That may possibly help to simplify the problem.

One does not like to be hypercritical in regard to such a good paper, but I want to draw the authors' attention to a few omissions before I sit down; some of them have been referred to by Mr. Duddell already. The first thing I notice is that a scale of current and a scale of time has been omitted from all the oscillograms given in the paper. It would be very interesting and would make the paper far more valuable if such scales could be added when the paper is printed in the Journal. The next thing I want to point out is that in all these oscillograms the practice should be to write the actual words which were spoken to the telephone, above the diagram as they are given by the authors in Fig. 2, and not as they are given in Fig. 1, in which, for example, they give the letter *e*. There are a great many *e*'s in the English language, and one wonders which it is. In Fig. 2 they show the right method when they say "*t* as in 'tea'"—and very interesting that oscillogram is. It represents the sound of the *word* "tea."

In conclusion, I can only, as an old experimenter, urge the authors of the paper to go on experimenting and measuring. There never was any progress in telephony or anything else until people began to measure, and if they will only go on measuring we may make progress. Experiments are costly; I do not know whether there are any here who hold the purse-strings of telephony, but if there are I would say, Go on finding the money.

Mr. Russell.

Mr. ALEXANDER RUSSELL: The paper is of value not only to telephone engineers, but also to those engaged in the problem of the transmission of power by polyphase currents. The equations are practically the same in the two cases, and the solutions given in the Appendix are of equal value to both. There is one point, however, in connection with these equations which, so far as I am aware, has only been fully discussed by Dr. Oliver Heaviside. The solution which the authors give is only the particular integral representing the forced vibrations of the system, and is the one applicable to their tests. When we consider the everyday

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Mr. Russell.

working of the line, the effect of the complementary function has also to be considered. It seems to me that for heavy telephone cables these terms will show that considerable distortion of wave shape is produced at every alteration of the frequency of the current waves. In ordinary telephone cables the time constant L/R is so small that the complementary terms are damped out with extreme rapidity. It is only when the time constant is appreciable that working difficulties other than those due to attenuation will occur. The authors admit that the application of graphical methods to the curves shown in Fig. 5 is perhaps hardly admissible. I do not think that it would be safe to calculate any of the harmonics above the fifth by this method. In the example illustrated in Fig. 8 the authors have taken the inductance per mile to be negligibly small. In practice, I doubt whether it can ever be neglected. If we have two untwisted telephone wires parallel to one another, the minimum possible value of the inductance per mile is 0·6 of a millihenry, and of this inductance over a quarter is due to the lines of force in the wires themselves, as with currents of frequencies of 1,000 there is practically no skin effect with telephone wires. It would have been better to take L equal to 0·1 or 0·2 of a millihenry. The authors are to be warmly congratulated on the experimental results shown in Figs. 15 and 16. Considering the many variables employed, I think that the curves are in very satisfactory agreement with Heaviside's theory. The currents shown in Fig. 16 appear to me to be approaching their final steady value through a series of oscillations of continually diminishing amplitude. In Appendix C the authors prove that $i_s = (V/Z_0) \tanh (la)$ when the line is on open circuit. It is not difficult to show that the modulus of $\tanh (la)$ when the complex argument increases is a quantity that continually oscillates with diminishing amplitude backwards and forwards through unity, and it seems to me that this is what the curves illustrate. Mr. Cohen's barretter will be an acquisition both in the test-room and on the lecture table. The experiment the authors showed us last week illustrating how the values of the currents sent and received vary with the length of the line will be most instructive for teaching purposes. I do not quite agree with the authors' remarks about an air-core transformer. These transformers may be clumsy, but they are not costly. At a frequency of 1,000 a shilling's worth of bell wire is all that is required for a 100-watt transformer. If the coils be made cylindrical in shape their inductance coefficients can be calculated without much difficulty with a maximum inaccuracy of less than 1 per cent. by the formulæ given in the *Phil. Mag.* for April, 1907. The method of finding the constants of a telephone cable given in Appendix E. is extremely neat. I hope the authors will obtain good results by this method in practice. Before sitting down I should like to direct the attention of those interested in telephonic transmission to the valuable series of papers by Professor Poincaré.* Amongst other important theorems he calculates the eddy-current losses in the

* *l'Eclairage Electrique*, vol. 50, 1907.

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Mr. Russell. diaphragm of the receiver and shows that they have an important effect on the working of the instrument. He also proves that the wave distortion produced by the hysteresis of the core is negligibly small. Mr. Campbell showed us last week how mechanical resonance sometimes occurs with a solid back transmitter. Electro-mechanical resonance also occurs in the receiver diaphragm, and when the two are placed opposite to one another we get the humming telephone, the main facts in connection with which Mr. Gill explained to us some years ago. The fact that the apparent resistance and inductance of the telephone receiver and of the primary and secondary coils of the transmitter vary with the frequency is the chief difficulty in the way of obtaining the exact solution of the problem of the transmission of telephone waves.

Mr. Tandy. Mr. F. TANDY: I do not think the members of this Institution should allow themselves to be misled by undervaluing articulation in practical telephony. As a matter of fact, it is quite true that up to a certain length of line we can probably ignore some of the higher harmonics and distortion, but it is the distortion which limits speech at the commercial limit, especially on underground cables. I think the commercial limit at the present time with standard cable is from 45 to 50 miles, or thereabouts. But that commercial limit is fixed, not by the amount of current received, but by the fact that the current is distorted. From some observations I have made on this point, it is quite easy to increase the electromotive force impressed on the transmitter to such an extent that as much as 5 milliamperes can be received at the end of a similar type of cable of 100 miles in length. What do we get at the end of that 100 miles of cable? We get a curve in which the amplitude is represented by 5 milliamperes, *i.e.*, a current which is much greater than is required, but it is different in shape to that transmitted, and it is that feature which prevents practical speech being received. The introduction of inductance considerably improves the shape of the wave, and as the result thereof you get an increased length of cable over which you can speak. I therefore think we are quite right in putting in as much copper as is possible, because the commercial limit is not affected by the amount of current received, but by the shape of that current.

Although the authors have given a good deal of information as to the data underlying telephonic speech, it is to be regretted that they have not furnished that further information which would have enabled us to introduce inductance into our circuits more effectively. At the present time a lot of work has been done in that connection, but I am not aware that any real information has been given to practical telephonists, which would enable them to determine the right amount of inductance to put into a working circuit to give the very best result.

There is one point raised in the paper in reference to the efficiency of telephone transformers. The statement is made that the efficiency is of the order of 1 per cent. When a current is applied to a telephonic

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circuit, several things happen. If the conductor has a large amount of capacity, the current at the transmitting end is very much greater than if the capacity is small, but the current at the receiving end is smaller than it would be if the line had no capacity. What is regarded as the efficiency of the induction coil under those circumstances? Is the efficiency based on the transmitted current in the secondary circuit, or the received current at the end of the line? Mr. Tandy.

With regard to the introduction of inductance in telephone circuits, I have made a large number of observations, mainly of the qualitative character, and find that inductance actually decreases the transmitted current, but increases the received current under favourable conditions. I also found it increases the lag. It is rather to be regretted that the authors have not given us some quantitative measurements on those points.

A great deal has been said with regard to the consonant. In most of the curves which I have taken I have found that the consonant part is almost invariably connected with the vowel portion; and, further, that instead of it being an unimportant factor it seems to me to be a matter of considerable importance, because the amplitude in many cases is greater for the consonant than it is for the vowel portion.

Mr. D. H. KENNEDY: I have been waiting to hear whether any one would refer to the possibility of eliminating the human element at the sending end by the introduction of the use of a gramophone as a sending instrument. Experiments which I have made with the gramophone—using the gramophone to send into the telephone—have impressed me very much with the possibilities in that respect. I would like also to associate myself with what Mr. Tandy has just said as to the extreme desirability of spending money on long-distance circuits. Perhaps I can put it best by pointing out that, even in this country, the present combined commercial and physical limits can be exceeded. For instance, using the London to Glasgow heavy gauge line and then an almost equally heavy gauge line on to Aberdeen, we get very good speaking from London to Aberdeen, when the line is extended to Inverness we are just at the limit, and if 10 miles of London underground is added at this end we get outside the limit. That is to say, it is possible to speak from London to Inverness or from Aberdeen to, say, Croydon, but not from Croydon to Inverness. Similarly, we get very good speaking from London to Paris and on to Marseilles, but Nice is outside our limits. The whole of the factors must be taken into consideration, the commercial factor, which includes the cost of the line, the physical factor, and also the expertness of the user. I think it might be of interest if I said that it is an everyday occurrence in London for commercial firms to transmit from London to Paris as much as 1,200 words in six minutes, and that, they sometimes complain if, from any cause, they fail to get through so much. Mr. Kennedy.

Mr. W. J. THORROWGOOD: We have made a great many experiments on telephone lines up to 100 and 150 miles, and we get fair Mr. Thorrowgood.

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Mr. Thorrowgood.

results with iron wires. The experiments are not quite completed, but I would suggest from the experience we have gained that a length of iron wire could be put in instead of adding inductance coils to the copper circuit. It seems to me that the question of using iron line wires for telephone circuits from, say, 50 to 100 miles in length, has not received the attention it deserves.

Mr. Gill.

Mr. F. GILL: One thing I want to mention is that the art of telephony has, during the last seven or eight years, undergone an entire change, and I do not think that change is really appreciated even by telephone men. I think I am right in saying that it is certainly not appreciated by those who are outside the business. But the real point I want to mention is the question of the schools. So far as I am able to judge, the schools are not devoting any serious amount of attention to problems such as this, *i.e.*, wave propagation. I think I am right in saying that if a student goes out of a college to a dynamo works, a light station, or a traction station, he can carry some of the work he has done in the schools right into his new business. But if he goes to advanced telephone work, he is able to bring direct very little out of the schools into his work; I am not quite sure whether that applies to wireless telegraphy, because the schools are doing a good deal on that side. I do think the schools might give more attention to this subject. If you measure the size of a subject by the magnitude of the capital involved in it, surely the subject is worthy of the attention of the schools.

I do not think I am ignoring the claims of anybody if I say that, outside those actually engaged in the business, the art is really indebted to very few men. I mean this advanced work on the mathematical side. Heaviside, Blakesly, Pupin, and Kennelly are the only ones I can remember, and I do not think I am ignoring anybody; then, of course, the art owes very much to Duddell for his instruments. As a telephone man I should like to say—and I am sure all other telephone men would like to say the same thing—that it is high time we recognised Heaviside. For a long time Heaviside was ignored; he was even ridiculed, but during the last few years he has slipped into acknowledgment in a quiet, unostentatious way. I think it is time we let Heaviside know we recognise him. I do urge the schools very much indeed to devote attention to the study of this subject. They have splendid men and apparatus, and we want all the help they can give us.

Mr. Wakefield.

Mr. J. H. M. WAKEFIELD (*communicated*): Volume and articulation in my opinion are inseparable. The authors seem to contradict themselves in the first paragraph on page 510, "volume is the prime necessity," and the last paragraph on page 511, "speech became quite impossible, although the volume was still quite considerable." In a case in which I personally carried out tests the articulation was quite good although the volume was not pleasant over a distance of 132 miles of 100 lbs. (about 14 S.W.G.) underground conductor. In another series of tests of 200 lbs. (about 11 S.W.G.) and 100 lbs. over a distance of 42 miles,

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the volume in the case of the 200 lbs. was three or four times as great as the 100 lbs., but the articulation was as 2 : 1 respectively. Mr. Wakefield.

In the first series of tests mentioned above, carried out about three years ago over a distance of 88 miles, a comparison was made between 25, 35, and 45 millihenry coils placed at 1 mile intervals. The 45 millihenry coils gave the best results, and a distance of 176 miles of loaded cable plus aerial wires for about 182 miles was spoken over satisfactorily. The length of circuit over which speech was possible was increased two or three times by the insertion of inductance.

The question of the gauge of wire to be provided in cables carrying long distance trunks is an intricate one, because, as pointed out by Mr. Gavey, a circuit may be of any length up to, say, 1,000 miles. Difficulties in design and manufacture would no doubt arise if the exact gauge proper to each circuit were insisted upon.

Following up the remarks of Mr. Thorrowgood as the cost of 200 lbs. iron wire is about 34s. per loop mile cheaper than 40 lbs. bronze wire at the present time, and as iron wire is efficient up to a certain distance, there are, no doubt, many cases where it could be used with advantage for short-distance circuits which would not be connected to the general system, *e.g.*, private wires.

Mr. Laws Webb's remarks as regards the 800-lb. (about 4 S.W.G.) loop between London and Glasgow were referred to by Mr. Kennedy, and I am of opinion that a few more circuits of this gauge would be very acceptable to the general public, and would not be a source of financial loss to the authorities.

Mr. B. DAVIES (*communicated*): I fully realise the very considerable difficulties the authors have overcome in the production of figures which appear to agree well with theory. The mathematical treatment of this subject, as well as that of submarine telegraphy, is in advance of the experimental—a fact mainly due to the lack of methods of measurements. As the devising and the developing of new methods proceed, it is a great pleasure to realise how the theory is upheld at every turn. A part of this process of development is exhibited in this paper. Mr. Davies.

At the laboratory of the Submarine Telegraph Companies at Electra House, we have had the good fortune recently of watching this same process in connection with submarine cables. It is interesting to note that, though the theory underlying the action of the submarine cable is identical with that governing the action of the telephone line, the measuring instruments and the measuring methods are very different. This is due to the large S.R. and low frequency on the one hand, and the low S.R. and high frequency on the other.

Personally, I am not strongly in favour of the bolometer in any form. In the hands of good experimentalists it can give good results, as the present paper proves, but the method is laborious and involves considerable time, and I always feel that at an early date it will be superseded by a more direct method, such as that afforded by the Duddell galvanometer. This instrument is capable of giving excellent

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Mr. Davies. results. Its one trouble from the author's point of view, is due, I should imagine, to the pendular motion of the suspended system, arising from mechanical vibration, and perhaps also to air currents from the heater. When these difficulties are absent, the instrument works well, and gives directly, of course, and quickly, the desired results.

I should like to express an opinion with regard to the action of the inductance coils which the authors use for choking the alternating current and preventing it traversing the galvanometer branch. In order to deal with a note of 200 per sec.—a usual note in the human voice—the two choking inductances in series must mount to several henrys. Thus, if the inductance be 10 henrys, its impedance will be $p\,L = 200 \times 6{\cdot}3 \times 10 = 12{,}000$ ohms nearly (if the resistance is negligible). Now, if the combined impedance of the bolometer and its shunt be 400 ohms, the leakage current will be to the measured current as 1 : 30. But such an inductance must involve considerable electrostatic capacity, which may possibly reach one-tenth microfarad. The electrostatic impedance of this, for a note of 1,600 per sec., is approximately 1,000 ohms. Since the impedance of the bolometer and its shunt is assumed to be unaltered, viz., 400 ohms, the leakage current in this case amounts to $\frac{400}{1000}$, or two-fifths of that measured. And for the really shrill notes of the human voice, say 3,000 a sec., nearly half of the current it involves would pass *viâ* the galvanometer, avoiding the bolometer. The authors no doubt have seen to this, but the point is not mentioned in the paper.

The results in Fig. 2 given by the human voice curves are most interesting. The *silent interval* between the high frequency effect of the explosive consonant and the beginning of the vowel formation is a striking feature of human speech, the *k* or *c* (first curve, Fig. 2) is formed entirely in the mouth, but the *u* is given by the glottis. The message announcing the end of the explosion must be conveyed to the brain along one set of nerves, and along another set the command is given for the glottis to act. But even after the command is received by the glottis, an interval is required to set this instrument in vibration. The sum of these two intervals, probably, represents the silent period in the curve. At the junction of *u* and *r* in the same word, the previous reasoning apparently does not apply, for the *u* may be uttered simultaneously with the trill of the *r*, because they are produced by two different instruments which do not interfere with one another. "Pea" and "tea" have also the silent epoch, with apparently the same meaning. The consonant *p* and the consonant *t* must end before the rush of air through the glottis can commence, hence the silent epoch.

One naturally predicts important results from this investigation of the characteristics of human speech, and we are glad that the Duddell vibrator has performed so good a service in the authors' hands.

I fear, however, that much of the complexity we perceive in these curves is due to the idiosyncrasies of the microphone. The authors do not appear to have tried an originally perfect sine-wave source in

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front of the transmitter and determine what relation the interpreted wave bears to the original, when all electrical reactance in the microphone circuit is negligible. Mr. Davies.

One is always hoping that one day a better and a more faithful reproducer of the human speech may be discovered than the carbon microphone. The loss of definition in the process of conversion of aerial waves into electrical impulses in the microphone is really considerable, as is proved by the process of retransmission through a second microphone.

The authors have probably tried a transformer method for measuring a simple sine current in a line. I mean the method strongly advocated by Mr. Albert Campbell, using an electrostatic voltmeter in the secondary. My colleague, Mr. Elton Young, and myself have tried this method for the submarine cable, but found that the inductance required in the primary was so large owing to the low frequency we were tied to that the introduction of the instrument disturbed the line conditions excessively. With the frequency of 100 a second and moderate power, the method works well, and it may possibly work well at a 1,000 with a small available power.

Messrs. COHEN and SHEPHERD (*in reply*): This paper has resulted in quite a long and interesting discussion, and the authors wish to thank the various speakers, and those who have sent communications, for the very kind and complimentary manner in which they have received it. Messrs. Cohen and Shepherd.

Mr. Campbell stated that the decrease in insulation resistance with alternating current has been noticed by him in the case of cellulose. We are pleased to have this confirmation. Mr. Campbell's interesting experiment shows that some transmitters resonate strongly to certain frequencies, a phenomenon already well known in the receiver; and Heaviside has pointed out that the line can resonate also. All this goes to confirm what so many speakers have mentioned here, that the ear must be a very wonderful instrument to analyse the resulting vibrations. Mr. Kingsbury seems to think that the consonants will look after themselves if the vowels are taken care of. It is not at all clear to us, however, how far this is true. Take the Welsh language for example. It must be remembered that, when carrying out telephone articulation tests, such consonants as *b*, *p*, *d*, and *t* get mixed up very early in the tests, and that, as the articulation is rendered worse, the vowels appear to begin to fail. But apparently, as far as our experience goes, it is the consonants that fail first. Mr. Elton Young considered that more attention should be paid to maintaining distortionless circuits by means of leakage, but the problem is different in telephony to that met with in telegraphy. Leakage is scarcely applicable to ordinary telephone cables; for example, the distortionless condition for 20-lb. conductor cable works out at about 200 ohms insulation per mile, but the attenuation is increased six-fold for a very trifling gain in articulation. In the case of 10-lb. light conductor cable of 190 ohms resistance per mile, and 0·07 microfarad, a still larger

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Messrs. Cohen and Shepherd.

reduction in insulation is required. Of course, when one comes to heavy aerial conductors, the distortionless point can be reached at a very much higher insulation resistance. With 400 lbs. aerial circuit it comes out at 85,000 ohms per mile, and the increase in attenuation is only 1·9 times. There may be some real improvement in transmission in this latter instance. Mr. Gavey asked a question as to the speed of the oscillograms shown by us. They were probably taken at a much slower speed than those illustrated in his paper. Mr. Gavey also asked what frequencies we should take in practice as the average and the highest important. We should certainly take the two figures given on page 512, 800 frequency for the average, and from 1,100 to 1,500 frequency for the highest in commercial talk. Mr. Gavey also asked whether speech was at all possible with 4-mile spacing of loading coils in the curve given in Fig. 9. The answer to that is "No." It was quite impracticable, though well-known words and phrases spoken slowly and distinctly perhaps might be recognised by experts. Mr. Hill asked whether transmitter distortion might not counteract the line distortion. This, however, appears almost inconceivable, and anyway there is, of course, no relationship between the two effects, though there may be accidental coincidence sometimes.

Various transmitters were employed during the course of these experiments, also different mileages of line, and, as might be expected, results of very diverse nature were obtained. We are not, however, able to enlarge upon the very mixed-up question of distortion at the present moment. Mr. Hill asks why we conclude that harmonics above 1,600 $\sim$ may be dispensed with. The reply is that, if communication through a circuit, which sharply discriminates against all frequencies above 1,600 $\sim$, is sufficiently good for ordinary purposes, then those frequencies are not required.

With regard to Fourier's analyses of waves, these were greatly enlarged by optical projection and a mean line drawn.

As to mean frequency, while it is true that if 1,000 $\sim$ is taken as a maximum, that 800 $\sim$ is higher than the arithmetical mean, yet there seems no reason why the latter should exactly conform to the speaking mean frequency. With reference to the figures on page 519, the reduction in effective insulation was not taken into account, but would have made quite a negligible difference in this particular case.

The cable measured by Bela Gati and Dr. Breisig* had heavy conductors, and might well have been affected to the extent mentioned by Mr. Hill.

All voice tests have been made on long lines, and the effect of terminal impedances have been consequently minimised.

With regard to Mr. Duddell's remarks, all telephone engineers are greatly indebted to him for his two instruments, the oscillograph and the thermo-galvanometer. They are certainly both instruments with which we have been enabled to make satisfactory telephone measurements. It was very interesting to see Mr. Duddell's vowels and

* *Electrician*, vol. 58, 1906.

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Messrs. Cohen and Shepherd.

consonants, and to notice that they were similar to the ones we obtained. The "a" sound long as in "ah" is exactly the same as we get (it was reversed in the paper, but this has been rectified); the "e" and the "oo" are somewhat different. The "e" and the "oo" shown in the paper were both given with Mr. Cohen's voice, which differs considerably from Mr. Duddell's. There is a reversal on page 513 in all three cases—this was necessitated by the method employed. With regard to the power measurements, Mr. Duddell thought the 3-voltmeter method was better than the method we used. We have made a number of measurements with the 3-voltmeter method. Probably the results obtained with that method were somewhat more accurate than with the other method, but they took a longer time. We are very glad to hear that Mr. Duddell has succeeded in getting a 600-∾ frequency sine-wave alternator which gives a decent amount of power. What is wanted, however, for telephone work, is a machine giving up to 1,500 ∾. As he mentioned, the machine we have, has a very small output compared with its size. We have made some experiments with iron wire for barretters, but we were never very successful. The lamps we use are of a pattern which it is unlikely Mr. Duddell has tried, and they are considerably more sensitive than any of the ordinary pattern lamps. Mr. Taylor and Mr. Tandy are both very strong for articulation, and it is interesting to know that these gentlemen are both Post Office Engineers. When we mentioned in our paper that articulation was, to a great extent, negligible, we were referring there more particularly to the comparatively short local junction lines and subscribers' lines which form such an enormous portion, and such a very valuable portion of the telephone network in the country. When one comes to consider the trunk lines, then articulation undoubtedly will come in to a great extent, but we still consider that volume is the primary consideration, and we think that the tests that have been carried out at different times, and which Post Office Engineers have been concerned in also, have, to a very great extent, demonstrated this. The use of a loaded telephone line as a wave filter was mentioned by G. A. Campbell in a paper in the *Philosophical Magazine*. The arrangement, as employed by ourselves, consists of double wound loading coils, having an inductance of about 0·17 henry each, the two coils assisting each other, and across the junctions of the loading coils, condensers of from a quarter to half microfarad capacity are placed. We have also found it advantageous to have some amount of non-inductive resistance in series. This appears to make the filter more abrupt. The amount of inductance and capacity is determined by the limiting frequency. Mr. Taylor mentioned the thermo-galvanometer, and there appears to be a little misunderstanding there. It is not stated that the thermo-galvanometer was not so satisfactory, owing to its being a more sensitive instrument, but we found more trouble from external disturbance. The thermo-galvanometer is undoubtedly one of the best instruments that can be used for telephone measurement work. The barretter, as used by us,

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Messrs. Cohen and Shepherd.

was not used in order to measure currents in the way the thermo-galvanometer does, because it is a more awkward instrument to use for that purpose. The main idea of the barretter is to obtain a null method, and in that way to make a number of measurements with complex speech waves, using actual transmitters and the voice. We agree with Mr. Laws Webb's statements, and particularly with his concluding remark. With regard to Mr. Evershed's contribution, we certainly think that the oscillograms would be more useful with a scale at the side, and we have now attached figures giving the time in the majority of cases. It is interesting to recall Helmholtz's acoustical researches. Experiments made by the latter authority seem to show that shifting the phases of a number of component harmonic sounds has little effect upon the impression received by the ear, and, although we believe this is a controversial point, it would appear to bear out Mr. Evershed's remarks concerning orchestral music.

Mr. Russell raises the interesting question of natural vibrations in telephone lines. We are of the opinion that these can have very little effect in modifying the working theory, at least as regards the ordinary types of cables, and Mr. Russell himself mentions the principal reasons for this conclusion, viz., that the free vibrations must be very rapidly damped out, owing to their high frequencies. The matter deserves closer study in the case of heavy aerial lines and loaded lines, where the time-constant $\frac{L}{R}$ is of some magnitude. For ordinary cable attenuation calculations, the inductance which is usually of the order of one milli-henry per mile, may be safely neglected, though the reactance term may rise to some importance when the copper weight much exceeds, say, 40 lbs. per mile.

As regards the air-core transformer,* we are not quite satisfied that a suitable coil can be constructed as easily as Mr. Russell suggests. We are obliged to Mr. Russell for calling attention to the interesting series of articles by Poincaré on the theory of telephone receivers. Mr. Tandy asked for some information on the insertion of inductance into telephone lines. The insertion of inductance in telephone lines is a very big subject. The National Telephone Company has carried out a considerable amount of work on loading, information regarding which would really merit a paper to itself. Mr. Kennedy mentioned a gramaphone. We have used a gramaphone for numbers of experiments. The chief trouble we found was that special records would be necessary, as the ordinary records soon deteriorate to a very great extent, and the articulation in that case would decidedly become a factor to be dealt with. With regard to the case of speaking from Croydon to Inverness, we gather that, although the trunk is heavy, the speaking is beyond the commercial limit. This, however, does not

* Mr. Cohen, in his verbal reply, thought that Mr. Russell was referring to air-core inductances for loading lines, and with this misunderstanding stated that one objection to these coils was on the point of bulk. This, of course, does not apply within practical limits to the case of apparatus for experimental purposes.

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Messrs. Cohen and Shepherd.

necessarily mean that to rectify matters the gauge of the trunk itself must be increased. Thus, consider a case like the following: Suppose we have a total route distance of 1,020 miles, made up of 1,000 miles of 400-lb. aerial copper, plus, say, 20 miles of miscellaneous urban underground connections equivalent to 10 miles of the standard cable. The talking value of such a circuit would be equal to about 48 miles of 20-lb. cable, and is, therefore, just beyond the commercial limit; in other words, the effective weight per mile of the whole lines is really only 300 lbs. Surely the most obvious thing to do here is to endeavour by some means or other, such as loading, to render the short-cable sections less obtrusive, or better, to remove them altogether if in any way possible.

Mr. Kennedy also asked as to the lines of future progress. We may say we consider that the insertion of inductance and the study of the impedances of the terminal apparatus seem to indicate the most promising lines of progress. Mr. Thorrowgood mentioned the use of iron wire. This has been considered, and for quite a number of reasons is not generally satisfactory. Of course, under certain conditions and in favourable localities, it may very well pay to use iron wire. The question is one rather of engineering costs and the standard of transmission desired than of any moral objection to the use of iron.

Mr. Wakefield remarks upon an apparent contradiction, but he should note that the conditions referred to on page 511 represent an extreme case, which would not arise in practice. Here there is not a progressive attenuation of the higher tones, but practically a complete removal of all above a certain frequency. It is not quite plain what Mr. Wakefield means when he refers to "volume not being pleasant."

In reply to Mr. Davis, we can quite imagine that trouble will be experienced when using the barretter for frequencies much lower than telephone ones, owing to leakage through the inductances; the capacity of the inductances has to be diminished by subdividing them.

In conclusion, we would again thank the members of the Institution for the very kind and appreciative manner in which they have received this paper.

The President.

The PRESIDENT: I will now ask you to convey a vote of thanks to Messrs. Cohen and Shepherd for their valuable paper.

The resolution was carried by acclamation.

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Proceedings of the Four Hundred and Sixtieth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 16, 1907—Dr. R. T. Glazebrook, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on May 9, 1907, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

James Geo. McLean.

From the class of Associates to that of Members :—

Enrique W. Martin.	M. I. Railing.

Miles Walker.

From the class of Associates to that of Associate Members :—

John W. Griggs.	William Steuart.
Percy B. Hall.	Harry R. Wickins.
Thomas Plummer.	Harold Wragg.

From the class of Students to that of Associate Members :—

Allen R. Crane.	Percy S. Hudswell.
Fielder J. Hiss.	Alex. D. James.

Messrs. J. T. Morris and H. M. Sayers were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Arthur Green.	Harry Hirst.

John James Lyth.

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Donations to the *Library* were announced as having been received since the last meeting from C. H. Benjamin, A. Constable & Co., Ltd., The International Correspondence Schools, and Major W. A. J. O'Meara, C.M.G., to whom the thanks of the meeting were duly accorded.

The PRESIDENT announced the awards of premiums and scholarships (see page 685).

The discussion on Messrs. Cohen and Shepherd's paper was concluded (see page 544).

The meeting adjourned at 9.45.

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Proceedings of the Four Hundred and Sixty-first Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 23, 1907, Dr. R. T. GLAZEBROOK, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on May 16th were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

W. E. D. Duncan.

From the class of Associates to that of Associate Members :—

John W. Jack.
E. G. D. Mathews.
Arthur J. Cridge.
William F. Stamp.

From the class of Students to that of Associate Members :—

William A. Jones.

Messrs. J. N. Alty and L. T. Healy were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

J. Hally Craig.
Ralph Davenport Mershon.
A. J. J. Pfeiffer.

As Associate Members.

John Barnard.
Herbert Arthur Burson.
Henry Codd.
George Herbert Eaten.
Frederick William Gaskins.
Charles Gould.
William Grant.
George H. Lofts.
William Lunn.
William Rostern Morton.
Earl A. Petithory.

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As Students.

Ernest Henry Child.	Charles Howard Harvey.
William Meggatt Dempster.	Murray Wood Martin.

Joseph Vincent Rugeroni.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Blackie & Son, Ltd., J. Gavey, C.B., The India Rubber, Gutta Percha, and Telegraph Works Co., Ltd., A. Marson; to the *Building Fund* from J. R. Andrew, R. C. Barker, J. R. Bedford, A. D. Constable, C. V. Drysdale, K. W. E. Edgcumbe, S. Z. de Ferranti, Col. H. S. Hassard, Lord Kelvin, A. E. Levin, W. M. Mordey, A. P. Pyne, J. F. C. Snell, A. Stroh; and to the *Benevolent Fund* from G. F. Allom, Sir B. Baker, Major P. Cardew, M. S. Chambers, W. C. Clinton, P. R. Cobb, Y. K. Cornish, H. C. Donovan, C. V. Drysdale, K. W. E. Edgcumbe, E. Garcke, Dr. Glazebrook, F. E. Gripper, H. G. Harris, Col. Hassard, C. C. Hawkins, J. S. Highfield, E. S. Jacob, Lord Kelvin, A. E. Levin, E. Manville, W. M. Mordey, Hon. C. A. Parsons, W. H. Patchell, A. H. Preece, T. Rich, S. R. Roget, G. H. Sayers, W. N. Scott, A. Siemens, A. Stroh, A. J. Stubbs, A. P. Trotter, H. J. Wagg, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: Since our last meeting engineering science, and every one connected with engineering in England, has suffered a very great loss through the sudden death of Sir Benjamin Baker. You will, I am sure, endorse the action of the Council this afternoon in sending a vote of condolence to the relatives of Sir Benjamin Baker, expressing their deep sympathy and their sense of the great loss that has been sustained by his death. It was my sad privilege yesterday, as your representative, to attend the memorial ceremony at Pangbourne; I feel sure that all will appreciate that by his death a great man has passed away from us.

The following papers were read and discussed :—

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THE PRESENT STATE OF DIRECT CURRENT DESIGN AS INFLUENCED BY INTERPOLES.

By F. HANDLEY PAGE and FIELDER J. HISS, Students.

(Paper read May 23, 1907.)

SUMMARY.

Section I.—Introductory.

Section II.—Limits of D.C. Machinery.

1. Heating. (*a*) Armature. Iron loss calculation.
   Eddy loss in the copper.
   Estimation of temperature rise.
   (*b*) Field Coils. Table of results.
2. Commutation. (*a*) Constant speed machines.
   (*b*) Variable speed machines.

Section III.—Calculation of the Interpole Dimensions.

1. General principles.
2. Formulæ used.
3. Interpolar arc to be used. Relative advantages of wide and narrow arcs.
4. Axial length. Determined by space and density used.
5. Pole-shoes. Special forms to reduce leakage. Curves of flux distribution.
6. Pole cores.

Section IV.—Effect of the Interpole on D.C. Machinery.

1. Use of interpole advantageous for larger sizes of machinery.
2. Poles. Arguments in favour of square poles.
3. Number of poles.
4. Armature length. Most economical density.
5. Pole shoes arranged to give maximum magnetic reluctance to the armature flux.
6. Armature strength.
7. Slots.
8. Windings.
9. Air-gaps.
10. Commutators. Smaller commutator has the advantage of better cooling effect of lugs.
11. Efficiency. Better curve at lower loads.
12. Conclusions. Points in favour of interpoles.

Section V.—Modern Practice in Interpolar Design.

Various examples of machines, details tabulated in Table III.

APPENDICES I. AND II.

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I. Introductory.

The heavy drop in the selling prices of all types of electrical machinery which has taken place during the last six or seven years, due to the keen competition which has prevailed during this period, has resulted in the cheapening of manufacture, not only through the introduction of better shop methods, but also through better electrical design. That is, the increased economy of material, shown by the decreased weights of active iron and copper used, with an accompanying reduction in overall dimensions, is to be measured both by the saving in material and by the consequently smaller labour charges.

This improvement cannot be attributed to any radical changes or departures in design as, since the introduction of carbon brushes and multipolar field designs, there have been practically no new constructions used. It is entirely due to more careful attention paid to the detail work of the machine as evidenced by the improved commutating qualities, and by working closer to the heating limits; improvements which necessarily follow a better grasp of the principles underlying successful machine design and working operation.

The modern tendency is to work the machine right up to its heating limit, and by means of ample ventilation in both armature and field to use the minimum amount of copper and iron compatible with good mechanical design and running. One does not to-day come across those liberally designed field coils, say on a large multipolar dynamo, which do not heat under normal running conditions more than 30° to 40° F., an experience common enough only a few years ago. A liberal margin of copper on the field was allowed for contingencies, such as a greater exciting current than was predicted being found necessary on test. Manufacturers were content to avoid the possibility of overheating on the field, and made sure of it by using perhaps 15 per cent. more copper than was absolutely necessary, cool fields being often used to offset the bad impression created by a too hot commutator or armature!

The temperature rise allowed is not quite so strict, 70° F. replacing the 60° F. more commonly specified a few years back, and signs are not wanting to indicate a general movement towards 80° F. for revolving machinery, all these temperatures being measured thermometrically.

With the advent of turbo machines a new phase of electrical development was immediately entered upon. Successful operation was impossible without some special device for ensuring sparkless commutation, with the result that compensating windings and auxiliary poles were again introduced. The success which attended these old and previously discarded devices has led first to their adoption on variable speed D.C. motors, and latterly on constant speed machines, and they are especially valuable in cases where generators are required to do duty both on a traction and lighting load.

The authors are of opinion that a particularly interesting stage has

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been reached in the evolution of the direct-current machine, and though this paper does not pretend to be more than a statement of the present state of D.C. design, they do not plead any justification for its presentation, as the subject is of such great interest at the moment. They will endeavour to show how the development of the interpole machine has led to a better mechanical design which ensures a more efficient ventilation, to a lower works cost due to the greater saving in material, and finally to an improved efficiency curve and commutation over the whole range of loads.

II. The Output Limits of D.C. Machinery.

To effect the greatest saving by the use of interpoles one must consider the limits of the present machines and see by what rearrangement they can be extended. The heating limits are the same for all machines and will be considered under one heading; the sparking limits will be dealt with first as occurring in constant speed, secondly as occurring in variable speed machines.

Heating in Armature.—An accurate predetermination of the armature temperature rise is not an easy task owing to the great differences found between the calculated and the actual iron losses. If a careful study be made of the question it will be found that the question of agreement or disagreement depends to a great extent upon the amount the slots are touched up with a file or milled out, or, in other words, how much the discs are burred over and shorted on one another. The hysteresis and eddy losses when separated out invariably give one result, the hysteresis being approximately as calculated, the eddy loss being several times greater than that obtained by a transformer test. The value of this multiplier is not constant for any given armature, but increases with increase of flux, and appears to be due to a breaking down of the insulation between the discs at the burred edges. As the flux increases the number of short-circuit paths increase, and the eddy loss rises far more than in proportion to the square of the density.

In Fig. 1 are curves of the measured iron loss in two machines, A being for a 55-H.P. motor in which the core was carefully built up, and B for a 23-H.P. motor in which the slots were touched up with a file and the plates not so carefully assembled. The iron losses are actually greater in the smaller machine, and the shape of the two curves at once shows wherein the difference lies.

With a carefully built up armature the above multiplier is approximately 10 with normal full field densities, but it will rise to 20 or even 30 if much milling or filing is done. Results calculated with the lower value will be found to agree fairly well with the empirical curve proposed by Parshall and Hobart.

Eddy Loss in the Copper.—In addition to these actual iron losses, those losses must be taken into account which, often classified as iron losses, are yet in reality eddy losses in the copper bars in the slots. They may be ascribed either—

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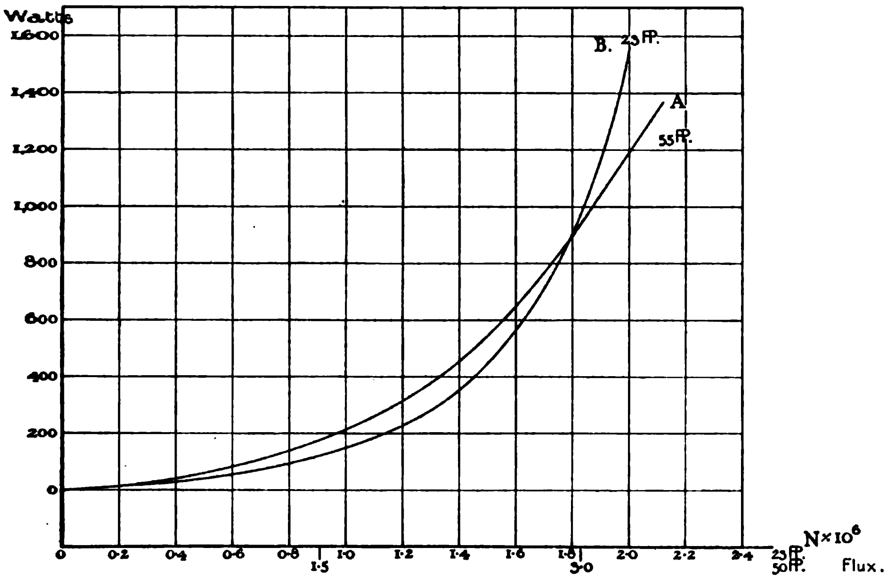

FIG. 1.—Iron Losses of 23 and 55 H.P. Motor.

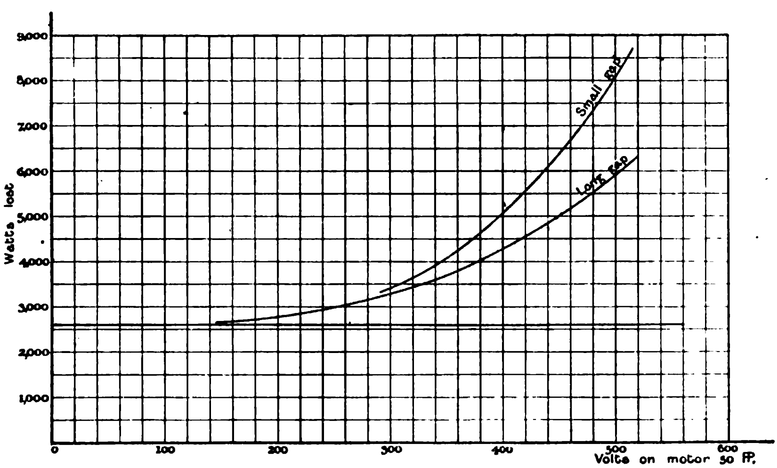

FIG. 2.—Iron Losses with Long and Short Gap.

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(1) To the increased fringe cutting the tops of the armature bars when the short air-gap is used, or

(2) To the varying reluctance of the magnetic circuit, the variation being greater the shorter the gap and the higher the density.

Fig. 2 shows the measured iron losses of an armature with an air-gap of 2 and 3·5 mm. The magnitude of the increase fully illustrates the importance of taking these details into consideration. To reduce these losses to a minimum it is advisable not to increase the tooth density above 21,000, and to work with gaps at least as large as those given in Fig. 15.

Estimation of Temperature Rise.—In calculating temperature rise for an armature the following formula has been used by the authors :—

$$\text{Temp. rise} = \frac{K \times W}{A \times (1 + 0{\cdot}1\, v)}$$

where K = constant
W = watts lost in the armature being the sum of the iron and copper losses.
A = cooling surface in square decimetres.
v = peripheral speed in metres per second.

The accuracy of the results obtained with this well-known method depends entirely upon the cooling surfaces taken into account. Fig. 3 shows these, the dark lines indicating the surfaces taken ; Table I. gives

TABLE I.

Watts Lost.			Radiating Surface.	Watts per Square Decimetre.	Peripheral Speed in Metres/Sec.	Rise °C.	K.
Iron.	Copper.	Total.	Dm.²				
255	246	501	38·1	13·20	15·30	23·50	4·54
255	288	543	38·1	14·25	14·60	29·00	5·02
255	365	621	38·1	16·30	15·00	30·50	4·70
100	271	371	38·1	9·75	7·80	27·00	4·95
100	420	520	38·1	13·70	8·02	39·50	5·23
235	470	705	48·1	14·70	13·30	32·50	5·20
240	271	511	48·1	10·50	13·40	24·50	5·40
110	418	528	48·1	11·00	9·80	34·00	6·15
160	459	619	48·1	12·80	12·05	35·20	6·05
195	405	600	48·1	12·50	10·65	39·60	6·55
500	645	1,145	59·0	19·40	13·05	40·50	4·80
165	579	745	59·0	12·60	7·10	39·20	5·30
230	770	1,000	59·0	16·90	7·14	63·50	6·40
225	610	835	59·0	10·30	7·52	27·00	3·30
166	573	740	59·0	9·70	7·81	35·80	5·10
154	610	764	59·0	10·30	7·90	36·50	5·02
270	585	855	59·0	9·90	8·45	31·50	4·00

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a series of results calculated by this method and the temperature rise obtained on test. Fig. 4 shows a series of curves which illustrate how this constant varies with the actual temperature rise of the machine, being higher the greater the rise and *vice versâ*. This shows that the higher the actual temperature rise, less watts per square decimetre per unit degree rise can be radiated.

TABLE II.

Radiating Surface.	Watts.	Watts per Dm.²	Temp. Rise Deg. C.	Constant.
34·70	170	4·90	22·5	8·72
37·35	136	3·64	24·8	5·86
34·70	156	4·50	33·2	5·42
34·70	151	4·35	22·7	7·70
46·60	261	5·62	32·2	6·96
44·80	274	6·10	41·5	5·90
44·80	268	6·00	34·7	6·90
44·80	219	4·87	32·0	6·10
44·80	186	4·17	38·5	4·34
61·80	336	5·45	25·0	8·20
61·80	348	5·65	34·5	6·56
68·75	247	3·58	36·7	3·90
68·75	238	3·47	37·5	3·70
68·75	256	3·72	32·0	4·65
68·75	261	3·80	18·9	8·00
68·75	265	3·86	27·8	5·55
68·75	270	3·93	41·5	3·80
68·75	260	3·79	32·0	4·74
68·75	191	2·78	31·5	3·54
68·75	251	3·66	29·5	4·95
70·80	322	4·65	35·5	5·15
174·90	382	2·18	18·0	4·85
164·50	608	3·70	29·0	5·10
164·50	690	4·20	40·5	4·15
164·50	680	4·14	41·2	4·03
164·50	731	4·43	39·0	4·56

The constant is the number of watts per square decimeter corresponding to 40° C. rise.

Heating in Field Coils.—A similar list of results for field coils, the whole surface being considered, is given in Table II., and a series of curves in Fig. 5. These curves have the same characteristics as those for the armature. In both cases it will be noted that the larger the size of the machine, the less is the variation in the value of the coefficient.

Commutation Limits in Constant Speed Machines.—The sparking limit of a machine is determined by the reactance voltage and the ratio, armature ampere-turns per pole : ampere turns per pole for gap and teeth. If the reactance voltage is sufficiently low, the latter ratio

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can be neglected, dependence no longer being placed on the magnetic fringe to reverse the current under the brush. Whilst this may be done with boosters and other low voltage machines, it is impossible to obtain the same state of affairs in a 500-volt generator. The higher the reactance voltage, the greater becomes the necessity for making sure that a distortion of the field at full load will not place the commutating coils in a field which will set up an E.M.F. tending to retard commutation. As the strength of the armature—ampere-bars per cm.

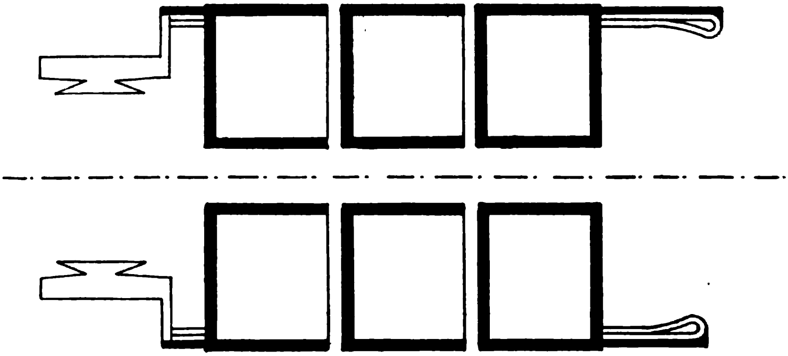

FIG. 3.—Cooling Surface of Armatures.

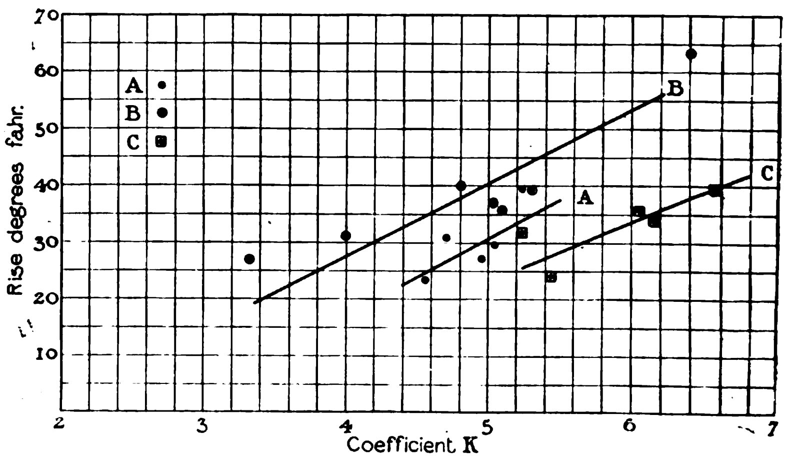

FIG 4.

of armature periphery—is increased, so must the gap or teeth ampere-turns in proportion be increased to ensure a fixed brush position from no load to full load. This entails a further expenditure of copper on the fields to provide the necessary extra ampere-turns, and a limit is reached about 260–300 ampere-bars per cm. of periphery, beyond which it is not economical to increase the output.

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The greater the core length the higher will be the value of the reactance voltage, owing to the decreased magnetic reluctance of the path of the short circuit flux. This in large machines considerably restricts the choice of armature length, compelling the choice of a larger diameter and smaller length than the most economical design would have given. The saving which is effected with the smaller diameter is considerable, owing to the decreased size of the overall dimensions of the machine.

Commutation Limits in Variable Speed Machines.—Variable speed shunt motors, with wide speed variation by alteration of the shunt

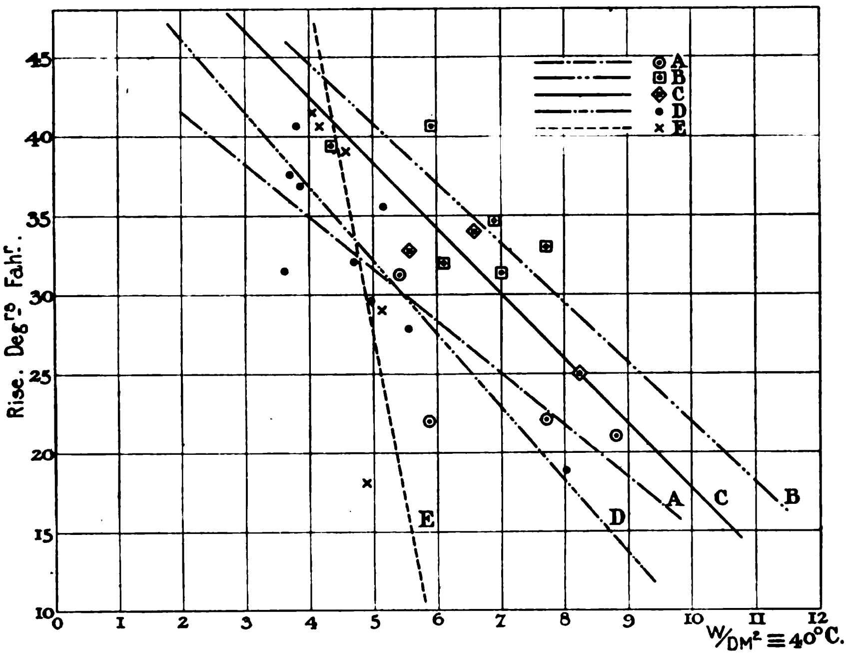

FIG. 5.—Temperature Rise and Watts per Dm.² Field Coils.

field alone, had been successfully built by a number of firms before the introduction of commutating poles.

The necessary means for obtaining good commutation under such stringent conditions are well understood. One must rely entirely upon the brush resistance to effect the reversal of the current, the brushes being placed in the geometrical neutral position, so as to minimise the effect of armature reaction.

In spite, however, of the low values of the reactance voltage which are obtained by the use of large commutators with many segments, etc., at the top speed, due regard must be paid to the distorting effect of the armature. Thus such machines, if a great range of speed

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variation be required, must be designed with a very high field strength obtained by the use of long air-gaps in conjunction with a normal armature reaction, and a smaller ratio of pole arc to pole pitch than is employed with the standard type of machine.

Up to 250 volts it was possible to obtain variations of 3 : 1 or even greater, but such machines were necessarily expensive, and with a 500-volt motor the great difficulty of obtaining a sufficiently low reactance voltage rendered the possibility of obtaining such a variation of speed entirely out of the question. The restrictions are, therefore, even greater with a variable speed machine than with an ordinary type, and if a case can be made out for the adoption of interpoles on constant speed generators or motors, they would be still more useful for variable speed work.

III. Calculation of the Interpole Dimensions and Windings.

The fundamental principles upon which the design of interpoles is based are well known to all. Sufficient ampere-turns must be provided to balance those of the armature, and, in addition, produce the necessary flux required for sparkless commutation. In practice, the design is not quite so simple as the above statement would lead one to expect, but by considering each part separately our task is rendered much easier.

Reactance Voltage.—In calculating reactance voltage and the turns required on the interpole, one of the authors has used either of the following methods, each of which has given satisfactory results, although the second one appears more rational.

The first method is due to Dr. Breslauer.* He takes as his basis the reactance voltage formula :—

$$e_r = \tfrac{1}{8}\, b^x \,.\, m_c \,.\, m \,.\, i \,.\, n \,.\, 10^{-8} \text{ volts.}$$

where e_r = reactance volts.
b^x = 0·1 mean length in cms. + net iron length.
m_c = conductors per armature coil.
m = conductors in series on armature.
i = current (total in armature).
n = r.p.m. of machine.

From this he deduces the following formula :—

$$A\,T_c = A\,T_2 + \frac{A\,S\,b_c}{2} + \frac{A\,S \,.\, 6 \,.\, \delta\, b^x}{1_c}$$

where $A\,T_c$ = total ampere-turns on commutating pole.
$A\,T_2$ = armature ampere-turns per pole.
$A\,S$ = ampere-bars per cm. of periphery of armature $= \dfrac{m \,.\, i}{\pi\, d}$.
δ = interpole gap.
b_c = breadth of commutating pole.
1_c = axial length of commutating pole.

* *Elektrotechnische Zeitschrift*, vol. 26, 1905, p. 640.

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The second term of the above equation requires some explanation. The auxiliary pole, being placed exactly over the coils undergoing commutation, tends to reduce the magnetic reluctance of the path of the short circuit flux. The second term was introduced to take this into account. In practice, however, it will be found that, owing to the damping effect of the eddy currents induced in the solid interpole shoes, this increase is to a great extent nullified. If laminated shoes are used, increased ampere-turns will be required.

In spite of this, good agreement will be obtained with this method between the calculated and the required interpole turns, as these ampere-turns provide the additional flux necessary owing to leakage.

The second method, which has also been found very reliable, is based on exactly the same principles as the above, the differences being in the calculation of the reluctance of the air-path, and in the reactance voltage formula used. Prenzlin's formula has been employed, and this is as follows :—

$$e_r = \frac{M_c}{2} \mathrm{A\,T}_2 \frac{n}{30.10^8} \frac{p}{\left(2 - \frac{a}{p}\right)a} \left\{ 1_a \left(1{\cdot}68 \frac{N_l}{N_b} + 3{\cdot}68 \log \frac{1}{N_b}\right) + 1_f \left(0{\cdot}1 + 0{\cdot}92 \log \frac{D_a}{p\,N_b}\right) \right\}$$

where p = number of pairs of poles.
$a = \frac{1}{2}$ number of circuits.
D_a = armature diameter.
1_a = length of armature iron net.
1_f = free length of conductor.
N_t = slot depth.
N_b = slot width.
1 = neutral zone.

From this is deduced—

$$\mathrm{A\,T\ required} = \mathrm{A\,T}_2 + \frac{\mathrm{A\,S}\,b_k}{2k} \times \frac{p}{\left(2 - \frac{a}{p}\right)a} \left\{ \text{a constant} \right\}$$

where $\frac{1}{k}$ = magnetic reluctance of the air-path, in centimetre units.

The method employed for calculating the magnetic reluctance is described later. This could, of course, be calculated in an exactly similar way to that used in the first equation. There it is assumed that the flux density is the same over the whole pole shoe; the magnetic reluctance is then equal to (in centimetre units)—

$$\frac{\text{Interpolar air-gap} \times 0{\cdot}8}{\text{Interpolar pole-shoe area}}.$$

We will now pass on to consider the interpole itself, and will first determine the pole arc to be used.

Interpolar Arc.—It is evident that a machine with a very narrow

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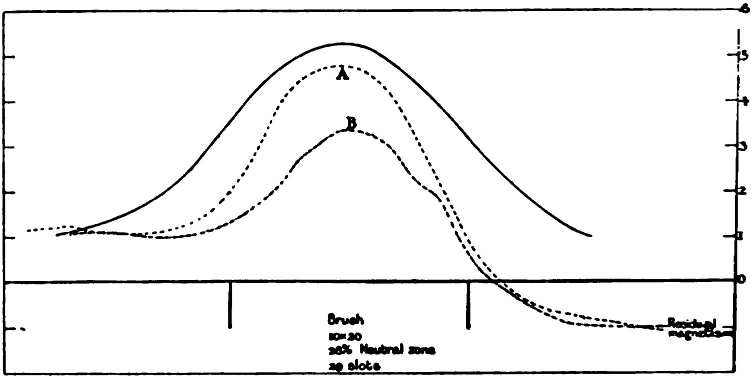

FIG. 6.—Interpole Field Distribution.

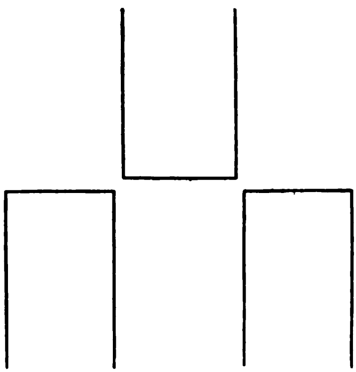

FIG. 7.

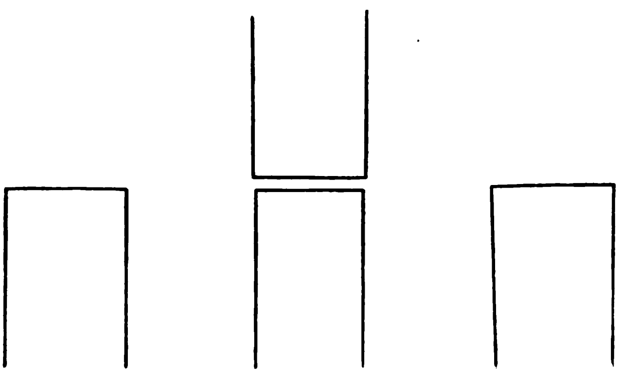

FIG. 8.

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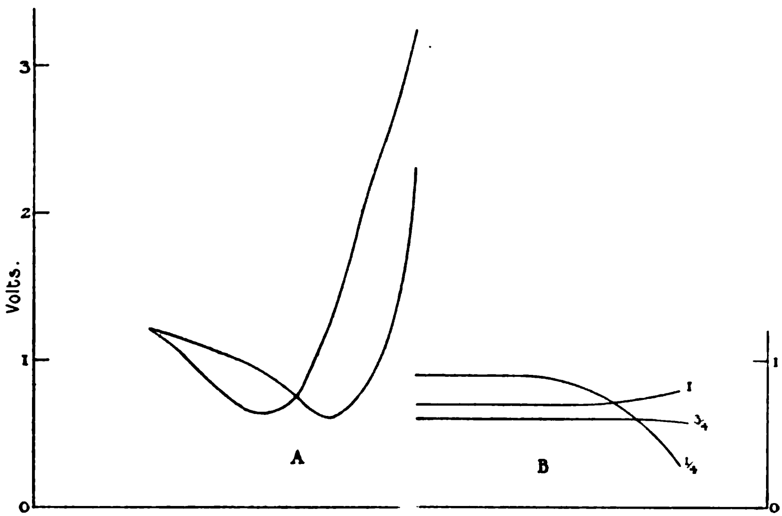
interpolar arc has many points in its favour. Owing to its comparatively small leakage coefficient, the machine will be able to stand heavy overloads without the interpoles becoming saturated, and the commutating field will be more closely proportional to the armature current. In addition, there will be more space between the auxiliary and main field coils, ensuring a lower temperature rise—with the same watts dissipated per unit of exposed surface—owing to the improved air circulation.

In Fig. 6 is shown the curve of interpole field distribution, with a machine where the arc is equal to the slot width. The dotted lines are the curves taken on test, the full lines are the calculated ones. The curve A was taken with 800 ampere-turns, curve B with 416



FIGS. 9 AND 10.—Brush Curves, Small and Large Interpole Arc.

ampere-turns, on the interpole. The arc subtended on the armature circumference by the brush is shown below.

It is obvious that part of the coils which are undergoing commutation must lie outside the influence of the interpolar field. By using brushes with a very high cross resistance it is possible even to obtain fair results with this narrow pole, but when a wide speed variation is desired on a 500-volt supply, or where the reactance voltage is higher than 3, it is impossible to obtain even this fair result.

It is not, then, so much the question of coils commuting outside the auxiliary field as it is the rapid variation of the field itself. Figs. 7 and 8 show this more plainly. The magnetic reluctance of the interpolar flux path will vary considerably as the teeth pass under the pole, being considerably greater in the case of the position in Fig. 7 than that in Fig. 8. To obtain fair results one has to take an average value

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for the commutating flux and then determine the ampere-turns required to produce this value with the average position assumed for the tooth. Fig. 9 gives the drop between the brush surface and the commutator of a dynamo with a narrow arc. Fig. 10 shows the curves at quarter and full load of one with a properly designed pole. The former very clearly shows the effect of the excess current which is flowing at the end of the commutation period, a feature which entirely disappears with the wider arc of Fig. 10.

These bad features are improved or made worse as the air-gap is increased or decreased; the flux variation being less and the fringing effect greater the longer the air-gap. It will be usually found that a machine with a narrow pole arc is very sensitive to brush position, being very liable to hunt or flash over with a sudden variation in load or speed. If, as is often the case, it is associated with a small number of slots per pole, there will be trouble at the commutator, every third segment or so being blackened according to the number of segments per slot. The machine may run satisfactorily on test or for a few weeks under actual working conditions, but slight sparking under the brush, hardly noticeable at first, will gradually become worse until the commutator blackens completely and the sparking is intolerable. This question of flux variation is again considered later on in the paper when dealing with series and parallel windings.

Arnold has stated that the width of the pole arc should be at least equal to two slot pitches, but this is not necessary with ordinary variable speed machines where the reactance voltage, calculated by Prenzlin's formula, does not exceed 8 to 9. An arc equal to a slot pitch plus a tooth width will be found sufficient; expressed in terms of a slot pitch this is equivalent to 1·5 to 1·7 times the pitch. It must not occupý too great a percentage of the neutral zone if leakage and, consequently, the interpole copper is to be kept within reasonable limits. For this reason 35 to 45 per cent. of the neutral zone will be found to be the average figures representing modern practice in this respect. The more difficult the commutating conditions, the wider should be the neutral zone and the greater the number of teeth per interpole arc. Still considering the same class of machines as above, 3½ to 4 slots per neutral zone is sufficient. The above conditions fulfilled, it is only necessary to see that the brush width is not too great or that the commutator diameter is not too much reduced so that the arc covered by the brush is too great; 25 per cent. of the neutral zone as the arc, subtended by the brush, will be found a very good working figure.

Axial Length.—The axial length of the auxiliary pole-shoe will be determined by the conditions which the machine has to fulfil, being dependent to a large extent upon the density employed in the air-gap. In high speed machines, or machines having a wide variation of speed, one must work with low average densities of from 5,000 to 9,000 lines per square centimetre in the air-gap, whilst with constant speed machines working at full field strength 10,000 to 12,000 will be perfectly satisfactory.

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It is best to cut down the axial length as much as possible, as thereby the leakage from the pole is reduced. When the average value of the flux per centimetre of periphery of the armature is found, this being determined from the reactance voltage, the length is settled by dividing the value obtained by the flux density most suitable for the conditions.

Pole-shoes.—Several firms have made a very special feature of the pole-shoe of the interpole, such as may be noted in machines built by the Phœnix and the Lahmeyer Companies. The first-named device is shown in Fig. 20, the second in Fig. 17, where it will be seen that a skewed pole-shoe is employed, this tending to reduce the variations in the flux. The utility of these devices depends upon the strength of the main fields; with variable speed machines they are of no avail, but they may have a certain sphere of usefulness with large constant speed generators.

In Fig. 11 are shown curves of field distribution of a dynamo with a rectangular interpolar shoe and concentric air-gap. A is the main field, B is the main and interpolar field, C_I is the main field with a current flowing through the armature corresponding to the B curve. C_{II} is the same as B, only the interpolar field is reversed. E is the field and armature field curve without any current in the auxiliary coils. It will be seen how closely this curve corresponds to C_{II} where the interpolar field replaces the armature field with very similar results. D and F are the same as B and C_I, only with double current flowing through the interpoles. At full load (curve C_I) there is no sign of distortion of the commutating field, and it is only at double overload (curve F) that the distorting effect of the armature really becomes serious. If we employ a sufficiently wide interpole or a narrow brush this trouble will be entirely eliminated, as we shall then keep the actual process of commutation between the limits X Y. The method of taking these curves is explained in Appendix II.

Pole Core.—The pole cores should be made circular in section wherever possible owing to the saving which can be effected in copper due to the decreased mean turn; this is not always possible owing to lack of room. A great difference in length between core and shoe is to be avoided, as it will lead to leakage and waste of copper. The core section is determined by considerations similar to those settling the axial pole-shoe length, and the shape by the space at disposal.

Number of Interpoles to be Employed.—With a series wound armature, the number of interpoles used need not be the same as that of the main poles, the improved ventilation obtained by such a construction being a great advantage.

From tests carried out by one of the authors it would appear that this method of design is not very general in its application. Its sphere of usefulness is limited to cases in which the reactance voltage is too high for successful operation with ordinary commutation methods, but where the main field is sufficiently strong to prevent serious distortion due to armature reaction. Successful operation cannot be so accu-

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rately predicted beforehand as in the case where the full number of poles is employed, and it would not appear that this method would be largely employed.

IV. The Effect of the Interpole upon the D.C. Machinery.

From a consideration of the principles outlined above it can be judged upon what lines the rearrangement of the design should proceed. It is evident that the heating limits will remain the same whether interpoles are employed or not, and it is only by a better distribution of the losses and a different proportioning of the various parts of the machine that an economy can be effected. For the very small sizes it is not probable that it will be found of much advantage to adopt commutating poles as a standard. The extra labour cost entailed in fitting commutating poles is of considerable consequence, the available space between the poles is constricted, the total number of field coils would be doubled, and, as the heating limit is reached before the sparking, advantage cannot be taken of the saving in material which is effected in large machines by a reduction in the length of the air-gap and so forth. Only machines above 40 to 50 k.w. output will therefore be considered in the following.

Poles.—The extensive adoption of interpole windings will probably decide once and for all the question of the shape of the main poles. Up to the present time there has been no consensus of opinion as to whether in general main poles of circular or rectangular shape should be chosen, makers of equal repute using poles of both sections on all sizes of machines. From the general standpoint the authors are of opinion that the cheapest designs are obtained by the use of round poles in bipolar and 4-pole machines, but rectangular ones for all machines with a larger number. The following argument may be adduced for the conclusions arrived at above.

A given diameter of armature having been chosen, the maximum flux per pole will be determined by the radial depth of armature core which can be allowed. This will be settled by the diameter of the shaft and the necessary allowance for the transverse ventilating holes in the core. With 4-pole machines this maximum flux can be easily obtained with round poles and the use of a rectangular section will only bring with it the attendant disadvantages of the greater mean length of turn and the extra cost of winding.

With large machines, where there is ample room inside the armature, it is found that with rectangular poles a much greater armature flux can be obtained, and thus for a given armature reaction a much greater output for the same size of machine is obtained. Although there will be a corresponding increase in the yoke and armature cross section, and in the field copper due to the increased mean turn, this design will be cheaper than one in which round poles are used, in addition to the fact that it will have smaller overall dimensions.

With interpole designs the question of space makes the employment

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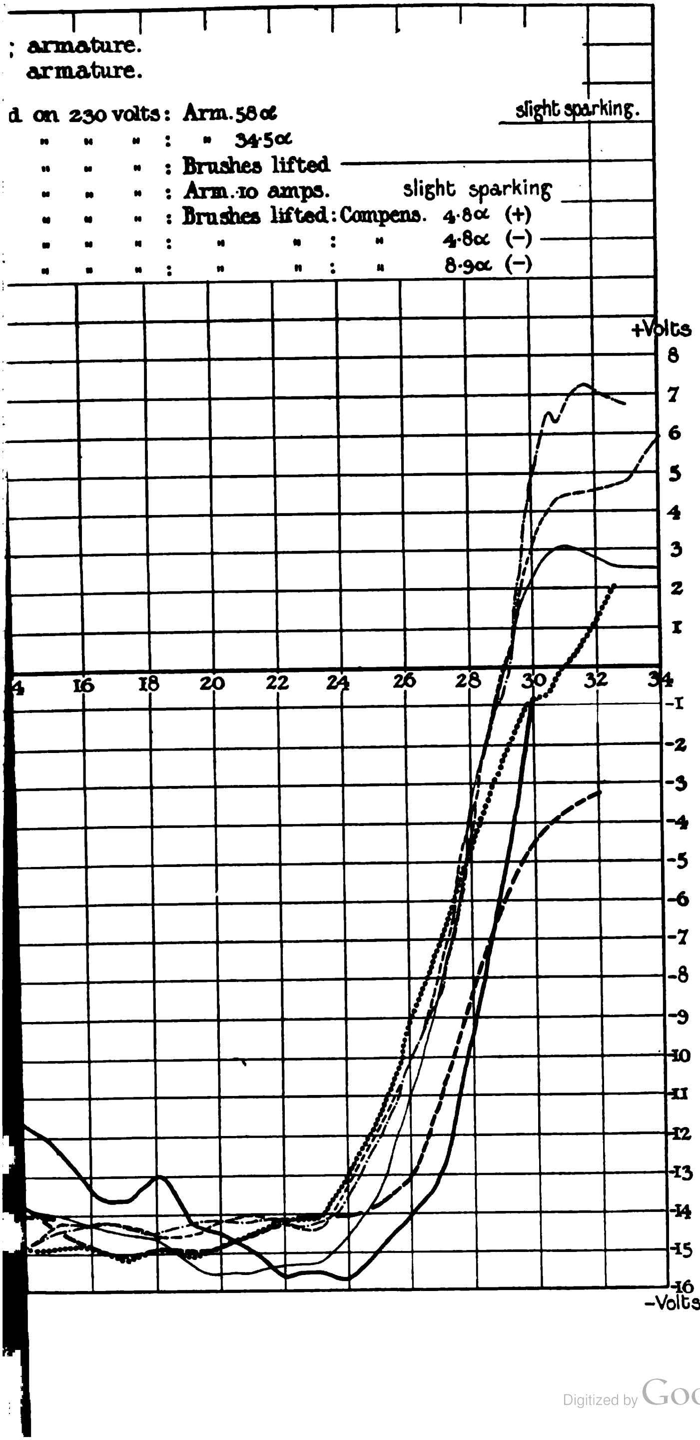

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of the rectangular pole even more necessary, and will no doubt lead to its use on smaller sizes than would be the case with ordinary machines.

Number of Poles.—It is this question of space as well as the application to the design of the conclusions drawn in Section III. which leads one to the result that it does not appear desirable to increase the number of poles with the new designs. Although on paper by so doing a considerable saving may be effected in amount of material used, yet the general sensitiveness of a machine with an abnormal number of poles fits it rather for laboratory experiments than for practical working, especially under adverse conditions.

This will be more clearly seen if the commutator is considered. The brushes will have to be narrower or they will cover a wider zone than the interpole arc, with all the resultant evils noted in Section III. The same amount of brush shifting will be relatively a greater percentage movement in the smaller neutral zone than where the number of poles is smaller. This is the cause of the extreme sensitiveness to brush shifting which is such a prominent feature of this class of design.

The difficulty of the increased number of segments no longer exists, as a much higher voltage per segment can be permitted, 20 to 25 volts per segment being successfully dealt with, without any tendency to flash over. This applies to ordinary D.C. generators, and not to high voltage machines with a wide range of speed variation, turbo machinery, or cases in which a high reactance voltage has to be dealt with at a very weak field.

Armature Length.—At first sight it would appear that a considerable saving could be effected in field copper by slightly increasing the core length of the machine and reducing the high flux densities in the teeth which are common in modern machines. This is possible, as one is no longer restricted in length by commutation conditions. A limit is, however, soon reached, beyond which a further increase in length is not economical. If this be exceeded it will pay to increase the densities again until the increased cost of copper as a per cent. of the total cost just balances the per cent. increase in output. This density seems to be about 19,500 to 20,500 lines per sq. cm., depending on the machine considered.

The greater flexibility in the matter of tooth densities is due, of course, to the fact that it is no longer necessary to have a stiff field to prevent distortion. The latter is by no means got rid of, as will be seen from Fig. 11, curve F, but is, in fact, greatly accentuated owing to the smaller air-gaps used. It is not a serious item with constant speed machines such as are built for direct coupling to high speed engines, but with turbo-generators or motors operating at high speed or with a wide variation of speed the overload which can be withstood is practically dependent on this. Flashing over at the commutator from one brush set to another—an experience only too common with turbo sets—is due to this, the volts per segment being enormously increased due to the distorting effect of the armature.

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Pole-shoes.—One method of reducing this evil to a minimum is that employed in a turbo-generator designed by Dr. Breslauer shown in Fig. 12, the air-gap being made greater at the edges than in the centre; the flux distribution obtained by this method is also shown.

At first it was thought that were it not for the question of humming the pole-shoes could be made without any chamfering at the tips, but this is not the case where the distorting effect is great and the reactance voltage high. The shape of the pole-shoes should be such as to give maximum magnetic reluctance for the path of the armature or cross flux so that the distorting effect is a minimum; it is therefore best, in addition to the long air-gap employed at the tips, to make the latter as narrow as possible.

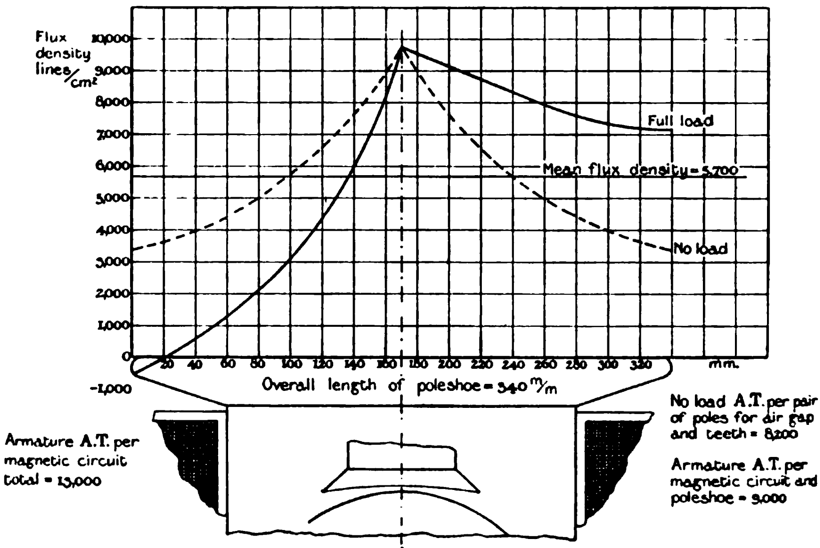

FIG. 12.—Field Distribution Turbo-Generator.

Slots.—In large machines where a deeper slot can be used without any appreciable diminution in the width of the slot, the output can be increased by putting more copper in the slot owing to the greater room in it.

Armature Strength.—It must not be forgotten that these increased armature ampere-turns will necessitate more interpole turns and that therefore there must be a certain point beyond which it will not pay to increase the rating even if there is ample room in the slot. This limit is reached when there are from 300 to 360 ampere-bars per cm. of armature circumference, the figure to be taken depending on the size of the machine.

Windings.—In the choice of windings one has now a much freer hand; a series winding can often be employed where formerly com-

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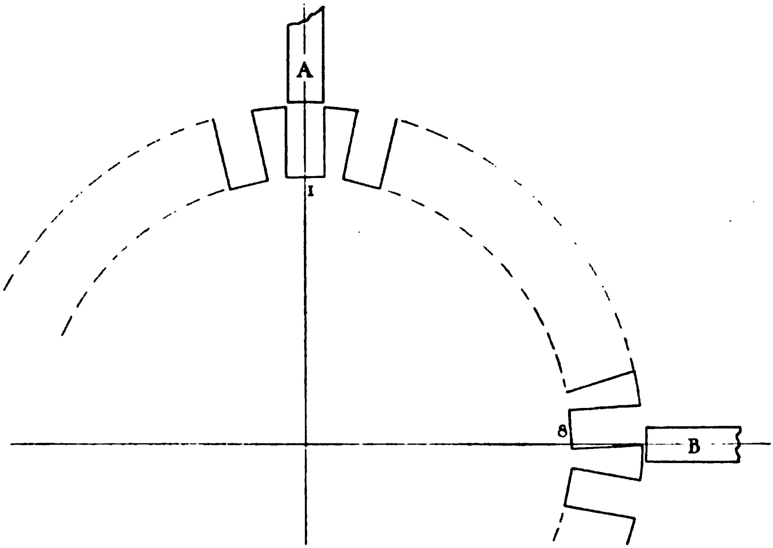

FIG. 13.

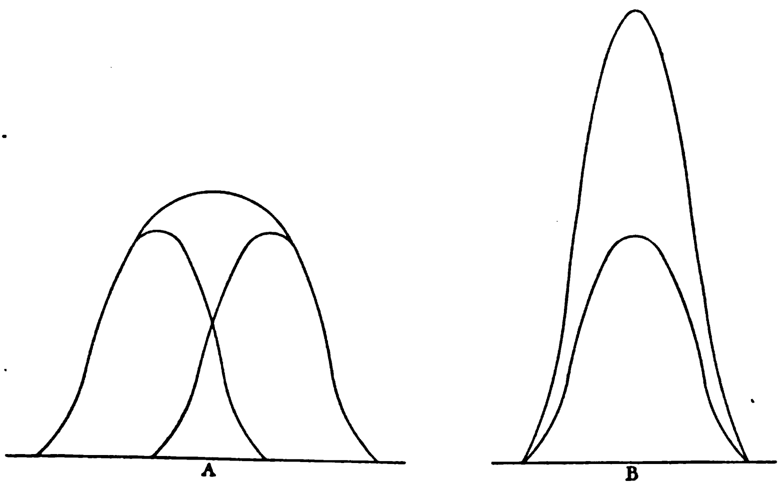

FIG. 14.

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mutating conditions would necessitate a parallel one. With interpole machines preference should always be given to a series winding, as its self equalising properties are very valuable with the short lengths of air-gap employed. Another important feature is that the variation in commutating flux is less with the series winding. Fig. 13 will make this more clear. Suppose a 4-pole machine with 29 slots and 6 coils per slot; the two pitches are $y_1 = y_2 = 43$, slot 1 to 8. When the centre of slot 1 coincides with the centre of pole A, slot 8, which contains the other side of the coil, will be a quarter of a slot pitch from the centre of pole B. The E.M.F. induced in the short circuited coil will be the sum of the E.M.F.s induced in the two sides of the coil. With an odd number of slots as above and a series winding these E.M.F.s will add up as in Fig. 14A, whereas in a parallel winding

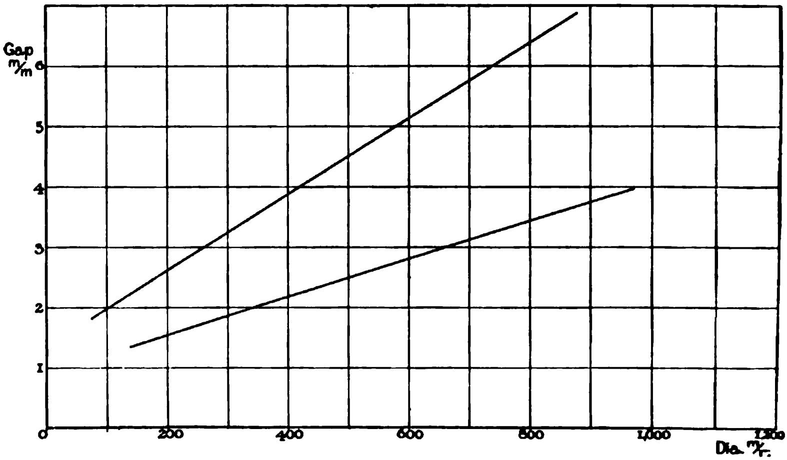

FIG. 15.—Air-gaps and Armature Diameters Interpole and Non-Interpole Machines.

where the number of slots is a multiple of the number of poles they will add up as in Fig. 14B.

It is this difference in phase between the two E.M.F.s which is equivalent to a widening of the pole arc, that led some early experimenters to declare in favour of a narrow pole arc, thus avoiding leakage troubles. The other troubles, such as blackening of the commutator and sensitiveness of brush position, eventually led to the abandonment of the narrow arc.

Series parallel windings should be avoided except in the cases mentioned below, as they usually lead to heavy equalising currents flowing under the brush from winding to winding. This will be very little improved by equalising connections. The only time when they can be employed with good results is with eight or a larger number of poles, a doubly re-entrant (ⓞ) or a duplex (oo) winding having been

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used with excellent results by one of the authors on several occasions. A doubly re-entrant winding is best with an 8, 12, or 16-pole machine; a duplex with a 10, 14, or 18 pole.

Air-gaps.—The question of air-gap length to be used has already been brought up in connection with the apparent iron losses of the armature, and has to be carefully considered as it is no longer necessary to use more than mechanical clearance demands. It must not be forgotten, however, that with a small gap, if the armature is slightly out of centre, big mechanical stresses will be set up due to the magnetic pull on the armature.

The curves in Fig. 15 represent the air-gaps which have been employed in ordinary non-interpole machines compared with the air-

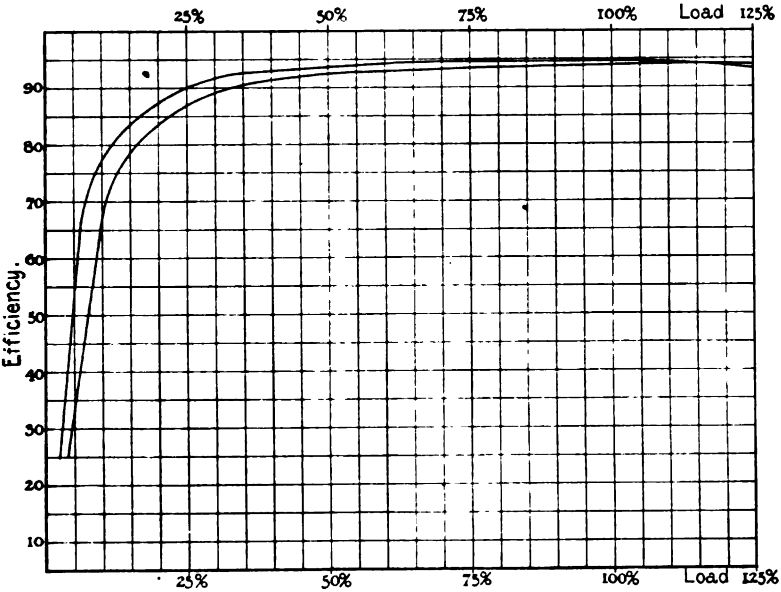

FIG. 16.—Efficiency Curves Interpole and Non-Interpole Machines.

gaps which the authors consider will be approximately adopted by most manufacturers who will take full advantage of the designs with commutating poles. Below these figures it is not advisable to go, for mechanical reasons, and above them the machine will be costly in amount of copper used.

Commutators.—One hears rumours on every hand of the great reduction in commutator diameters and lengths which have taken place since the introduction of the interpolar design, leading to a great saving in that expensive item—commutator copper. The reduction in the number of commutator segments has led designers to reduce the commutator diameter until with the maximum number of segments which would be used with the interpolar design, the pitch of the

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segments is the smallest permissible for mechanical reasons. The advantage gained is, to a certain extent, more apparent than real. With the smaller commutator the brushes must be narrower or the amount of the neutral zone covered by the brush will be too large, and owing to the decreased section more brushes per spindle will be required. This assumes that the same current density is employed in both cases.

One will very often find that for both the designs the area of the commutator is practically the same in both cases, and for the following reasons.

The C^2R loss will be approximately the same in both cases, being equal to twice the amperage of the machine, and the brush friction losses will not be sensibly reduced owing to the decreased peripheral speed of the smaller commutator.

Whether the two areas are the same or not depends upon the ventilation obtained through the lugs. If the decrease in diameter does not improve it, the areas are equal for equal temperature rise; when there are few segments, as in an interpole machine, and plenty of room between the lugs, the improved cooling effect will sometimes make it possible to dispense with one or more brushes per spindle and to obtain a corresponding reduction in commutator length.

A second point gained is where a certain wearing depth of commutator is specified (for example, 1 in.). Suppose two cases, a commutator 6 ins. diameter and 4 ins. long and one 8 ins. diameter and 3 ins. long, the exposed surface being the same in both cases. The volume of active copper in the first case is proportional to $\pi(3^2 - 2^2)4 = 20\pi$ in the second to $\pi(4^2 - 3^2)3 = 21\pi$. The mechanical construction is also cheaper with the smaller size.

Against these advantages must be set the fact that the smaller the commutator diameter the narrower must be the brushes and the more sensitive will be the machine to brush shifting. A ratio of 60 per cent. of armature diameter to commutator diameter appears to be quite low enough for true economy.

Efficiency.—As has been repeatedly pointed out by several writers, the efficiency curve is much improved at light loads with auxiliary designs. The constant losses are diminished, the iron losses being less, due to the decreased tooth densities, the excitation loss less, due to the decreased length of air-gap. In Fig. 16 are given the efficiency curves of two generators illustrating this point.

Conclusions.—The question which faces the manufacturer is whether auxiliary poles should be regarded merely as adjuncts to a standard line of machines, arrangements being made that they may be fitted to variable speed, variable voltage, and generally difficult cases with a minimum of cost, or whether new designs should be got out.

Reviewing the way in which the designs can be modified, it will be seen that all the following advantages, if to be made full use of, will demand a complete rearrangement of the design.

For large machines the works cost will be cheapened owing to—

(*a*) The higher armature reaction employed. The extra cost of

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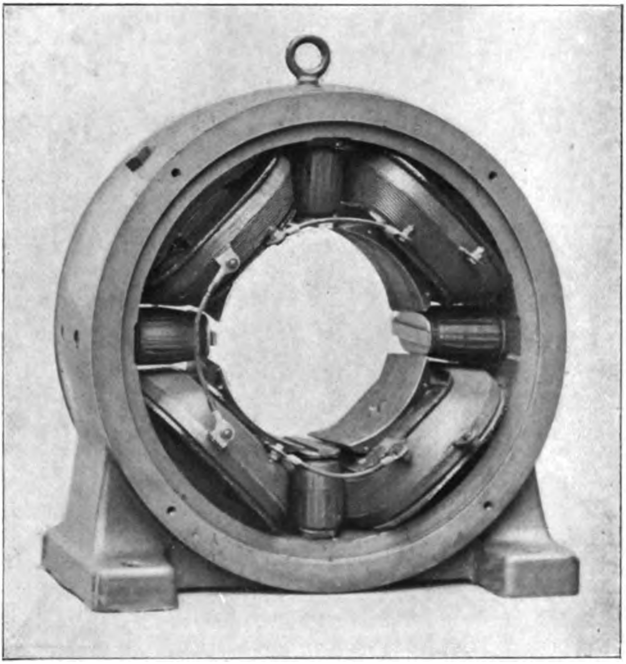

FIG. 17.—Field Magnet Frame, 7.5 H.P., 500 volt, 400/1,000 r.p.m.

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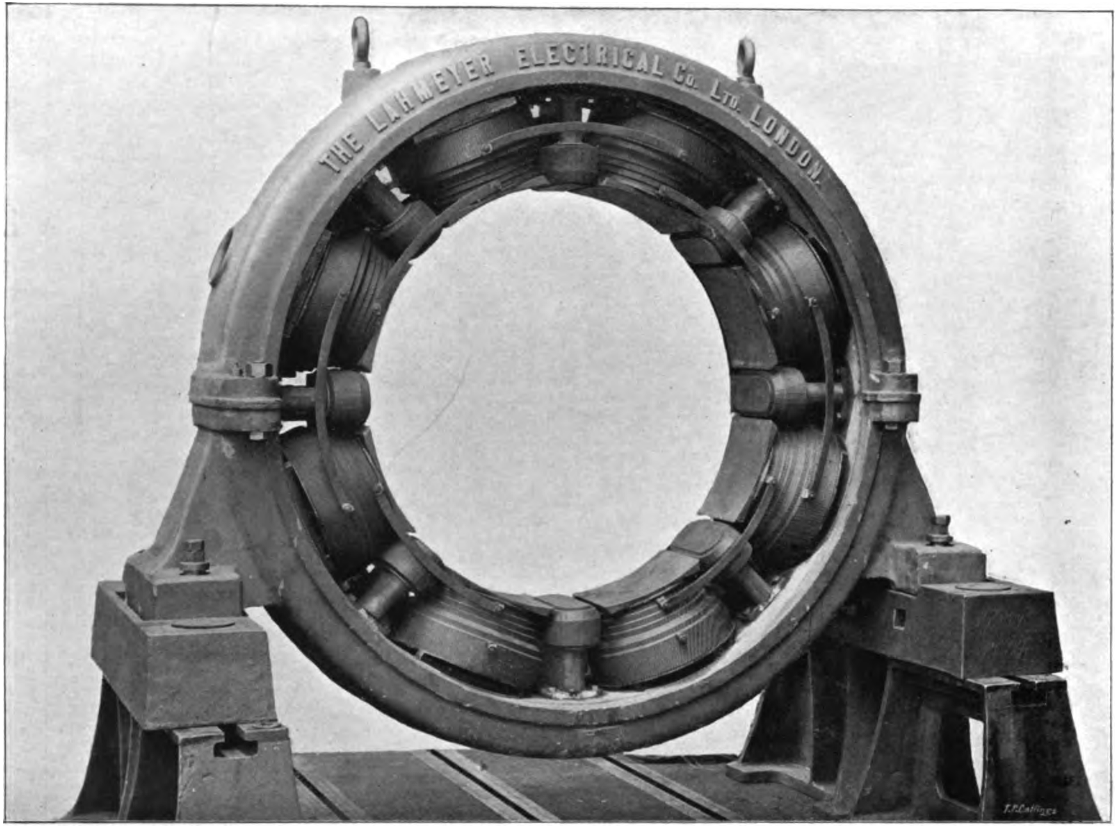

FIG. 18.—Field Magnet Frame, 360 H.P., 550 volts, 500 r.p.m.

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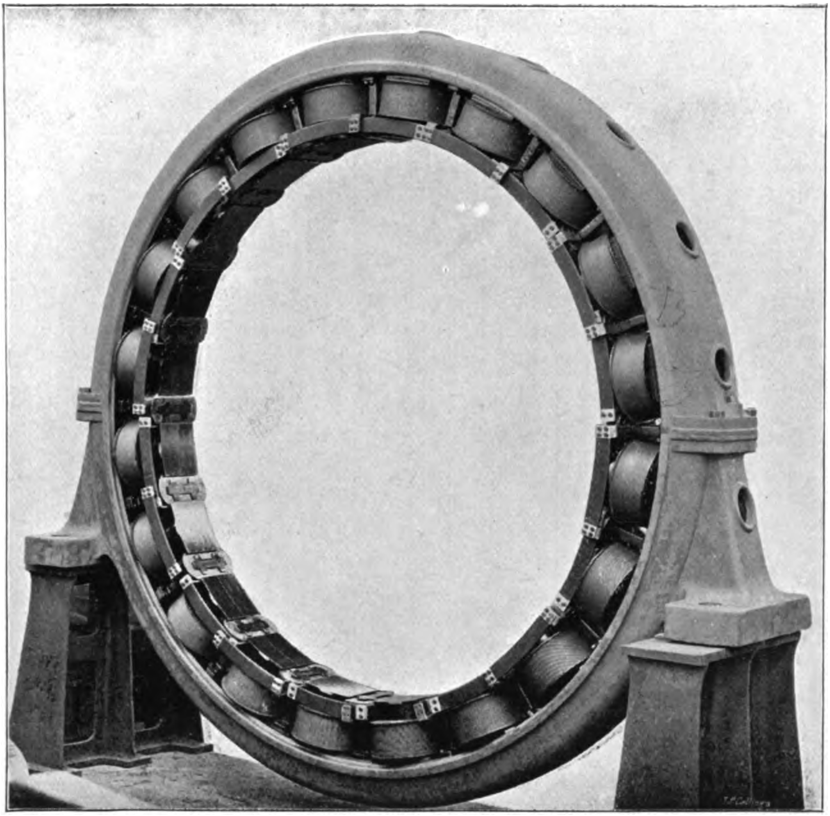

FIG. 19.—Field Magnet Frame, 1,100 k.w., 630 volts, 94 r.p.m.

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the interpole copper and winding being more than offset by the increased output obtained and the saving on the main field, no ampere-turns being required for armature reaction.

(*b*) The smaller air-gap. This still further reduces the amount of copper required.

(*c*) The armature can be made longer and of smaller diameter, thus effecting a great saving in the mechanical design and labour costs.

(*d*) A smaller commutator, giving a better ventilated armature and a cheaper mechanical construction.

The working qualities will be improved owing to

(*a*) The smaller number of segments, which will minimise the trouble so often experienced due to high micas or bars.

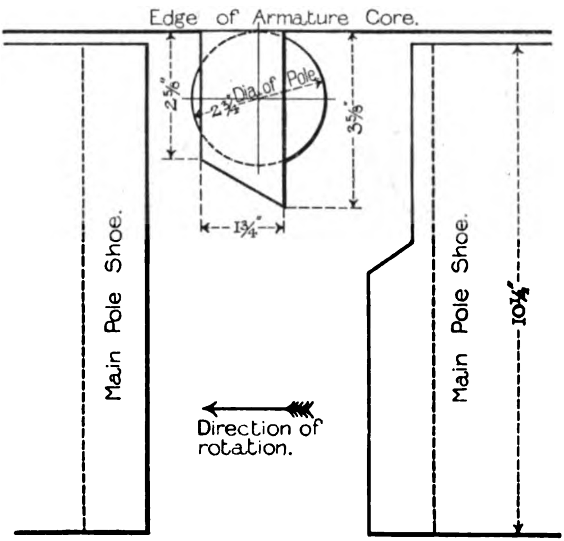

FIG. 20.—Auxiliary and Main Poles, 200 k.w., 500/540 volts, 400 r.p.m.

(*b*) Better commutating qualities, a properly designed machine giving no load to 50 per cent. load without shifting of the brushes or any signs of sparking.

(*c*) It follows that there will be less attention required at the commutator and less frequent renewal of brushes.

V. Modern Practice in D.C. Interpolar Design.

The following examples of machines will serve to illustrate the way in which manufacturers have taken up the question of the adoption of commutating poles. They are described separately under their various types, but for the sake of a better comparison are detailed out as far as possible in Table III.

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Fig. 17 illustrates a shunt motor by the Lahmeyer Company of 7·5 H.P., 500 volt, 400–1,000 r.p.m. This is a fair example of interpoles applied to a small machine, and one notes the use of tapered coils on the main poles to provide more room for the auxiliaries, and also the skewed form of pole-shoe referred to above.

In the type shown in Fig. 17 the poles are bolted on from the outside of the frame. A different method consists in fixing them from the inside.

Fig. 18 illustrates a motor of 360 H.P., 550 volts, 500 r.p.m. This is one of the Lahmeyer Company's latest types, and here the principle of tapered main coils and concentrated auxiliary coils is fully adopted.

Fig. 19 represents a dynamo of 1,100 k.w., 630 volts, 94 r.p.m., by the same company. The method of winding shown in Fig. 18 has

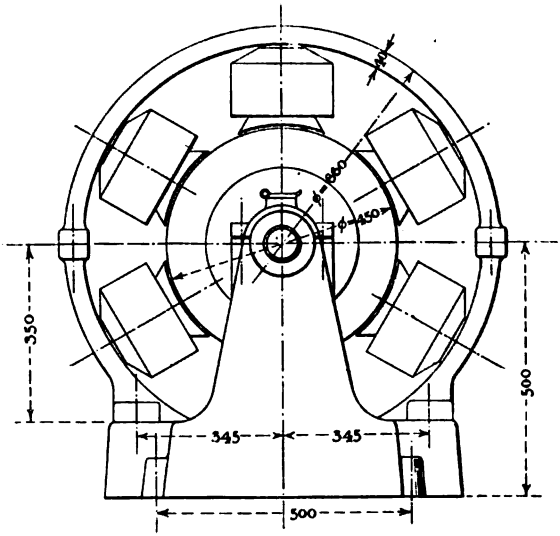

FIG. 21.—22 H.P., 180 volts, 300/1,100 r.p.m.

been carried still further, and the main coils are now only wound on a part of the pole, the rest being left bare to permit of more room for the commutating coils.

Details of a dynamo by the Phœnix Company of 200 k.w., 500-540 volts, 400 r.p.m., are shown in Fig. 20. The main pole-shoes are cut away on the one side to reduce leakage to a minimum. The auxiliary pole-shoe is given a special shape for the same reason. (For further details see Table III.)

Figs. 21 and 21A represent a motor of the Oerlikon Maschinenfabrik of 22 H.P., 180 volts, 300–1,100 r.p.m. Tapered main coils are used and also a small diameter commutator.

In Fig. 22 is illustrated a dynamo of 100 k.w., 500 volts, 400 r.p.m., from Siemens Bros.' Dynamo Works. A commutator of larger diameter

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has been used with this dynamo than with most interpolar designs. By the use of square poles full advantage is taken of the core; efficient ventilation of the coils is ensured by leaving the coils untaped.

Details of a dynamo of 115 k.w., 460 volts, 250 amperes, 550 r.p.m., by Kolben & Company, are given in Table III.

Fig. 23 gives details of a motor of 30 H.P., 440 volts, 230–800 r.p.m., by Lawrence Scott & Co. This machine was designed for constant torque at varying speed. This firm have kindly consented to the publication of their views on this question. They are not in favour of

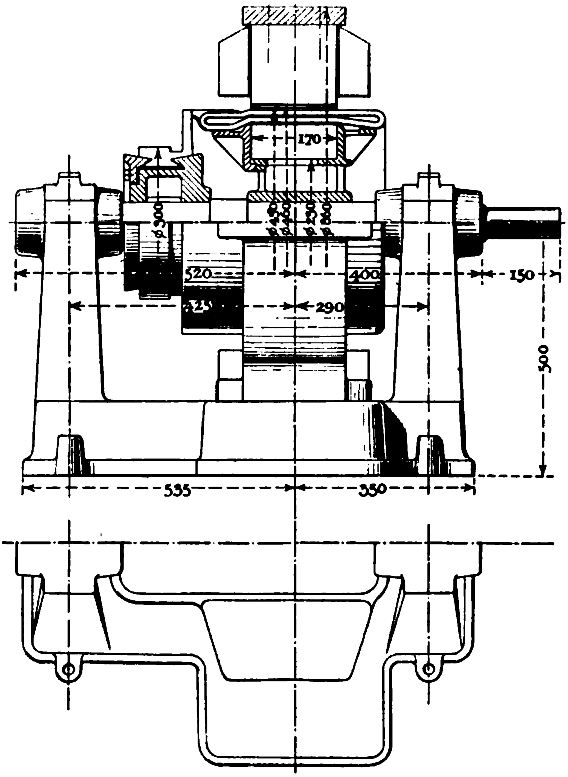

FIG. 21A.—22 H.P., 180 volts, 300/1,100 r.p.m.

interpoles for standard machines below 30 to 40 H.P., and do not fit them except in special cases of speed variation, etc. For larger machines, although of opinion that a considerable saving could be effected in iron, but not much in copper, the space occupied by the extra coils is great, and the complications involved go a long way to nullify the advantages of commutating poles. Their machines are designed to give satisfactory results without interpoles, and thus are not specially made for them.

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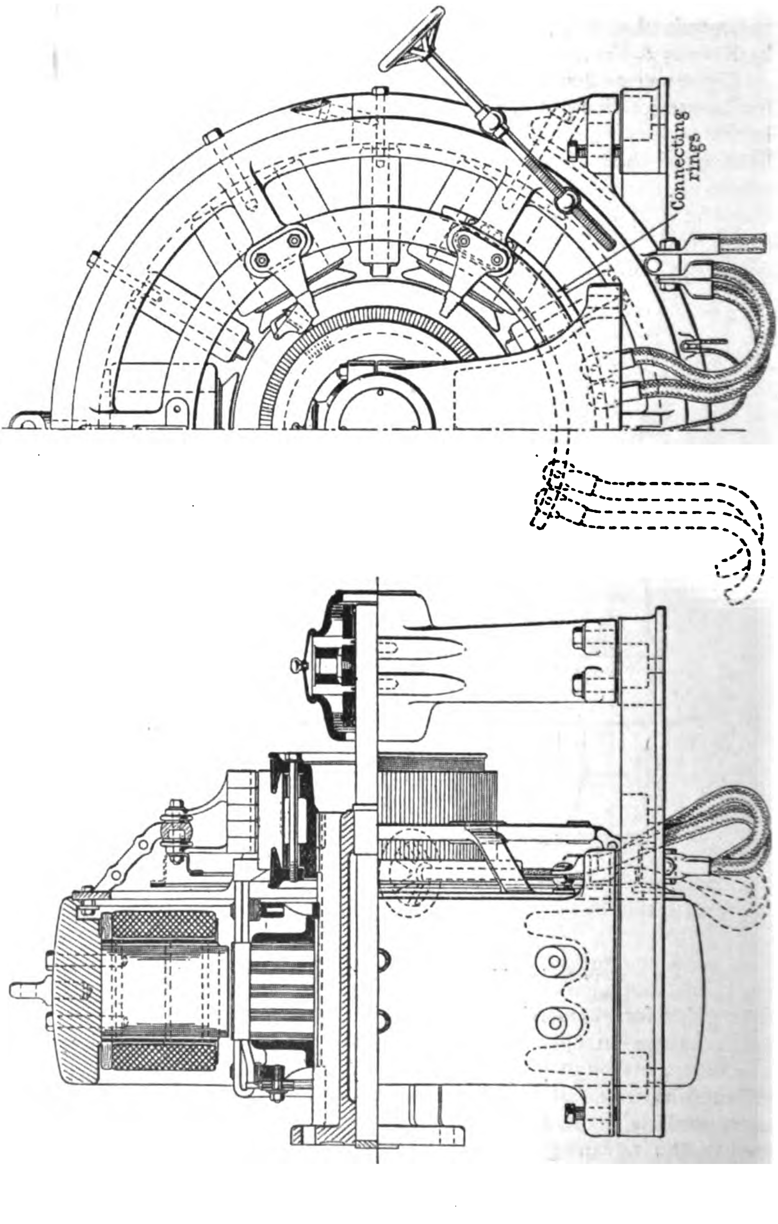

FIG. 22.—100 k.w., 500 volts, 400 r.p.m.

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Fig. 24 shows a 100-k.w. cascade converter by Brown-Boveri. This machine is noteworthy for the fact that only two instead of four interpoles are used. This is only possible with a series winding on the armature.

In the machines which one of the authors has designed for Johnson & Phillips, Ltd., square poles have been adopted so as to obtain the maximum use of the armature core; the interpoles are cast in with the yoke, thus avoiding the cost of machining and fitting.

An illustration is also presented of the field magnet yoke of a 125 k.w., 428 r.p.m., 550 volt machine, and of a drawing of the yoke of a smaller machine of 30 H.P., 800 r.p.m., 230 volts. In this size, the

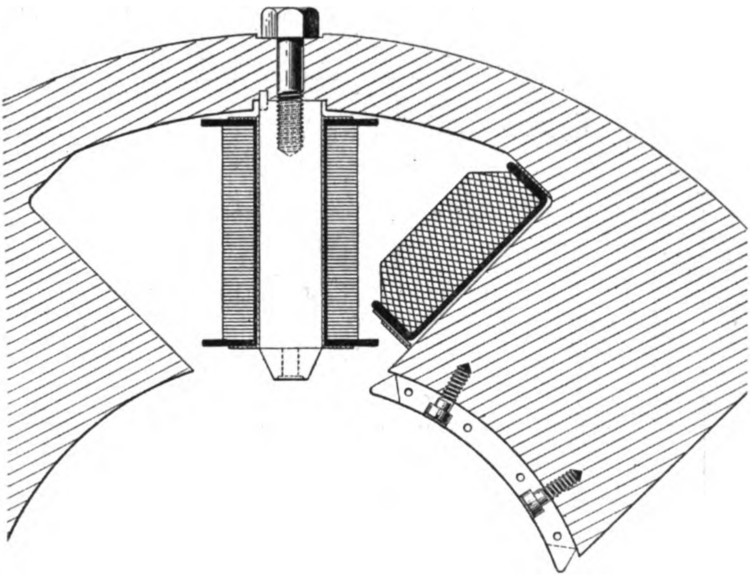

FIG. 23.—Auxiliary and Main Pole.

poles are bolted to the yoke, this being a case in which interpoles have been fitted to an ordinary machine.

Turbo-Generators.—In turbo machinery the great difficulty to contend with is distortion and its resultant evils. To overcome this the Deri compensating winding has been largely used, the armature reaction being neutralised by distributed windings in slots in the pole-shoe.

The following are two examples by Brown-Boveri of modern design :—

In these machines the Deri winding is employed, as will be seen from the sectional drawings Fig. 25 and the photographs Figs. 26 and 27, the former showing a wound and the latter an unwound carcase.

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TABLE III.

	Lawrence Scott & Co.	Kolben.	Breslauer.	Phœnix.	Oerlikon.	Johnson & Phillips, Ltd.	Brown-Boveri.
Poles	4	4	4	8	6	6	4
Output	30 H.P.	115 k.w.	2 H.P.	200 k.w.	22 H.P.	125 k.w.	250 k.w.
R.p.m.	230/800	550	1,350	400	300/1,100	428	500
Volts	440	460	440	500/540	180	550	500/600
Amperes	16/63	250	4·5	400/370	111/105	226	240/200
Armature (out) ϕ ... mm.	432	591	180	875	450	610	700
„ (in) ϕ ... „	190·5	328	90	—	250	—	381
Length ... ... „	254	320	90	270	170	235	330
Slot dimensions ... „	7·6 × 17·7	15 × 30	7·5 × 13·5	—	× 33	33 deep	× 31·7
Width Air-gap ... „	4·76 main.	4	0·6 — 1·6	—	—	—	—
	inter.	3	0·8	—	5	2·5 mm.	6·35
Interpole dimensions „	d = 50·8	d = 75	16 × 40	d = 70	—	101·6 × 38	70
„ section ... cm².	20·3	44	6·4	38·5	—	„	—
„ shoe area... ...	25·4 × 50·8	40 × 160	28 × 40	44·5 × —	—	„	— × 35/70
Commutator diameter mm.	356	—	—	—	300	380	530
Segments	267	201	—	111	—	—	—
Output coefficient	42·6	42·0	180·0	38·0	51·0	26·5	67·0
Ampere-bars per cm. ...	248	270	63	—	—	—	—
Flux per pole ÷ 10^6 ...	1·27 min.	—	—	—	—	—	—
	5·10 max.	6·55	0·512	—	—	—	—
Reactance voltage	0·837	1·72	0·6	—	—	—	—
	2·9	—	—	—	—	—	—
Interpole turns/pole ...	126	57	150	—	—	—	—
Strip	1·016 × 25·4	3·5 × 30	d = 1·3	—	—	—	—
Pole arc/pole pitch ...	0·65	0·69	0·65	0·75	—	75	0·68
Copper weight	454 lbs.	750	18·25	—	—	750 lbs.	—

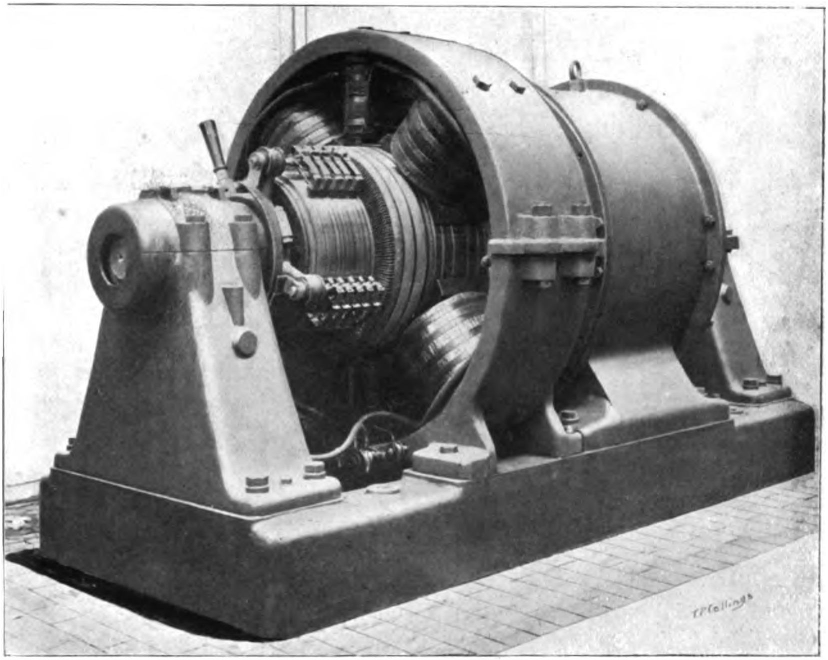

Fig. 24.—100-k.w. Cascade Converter.

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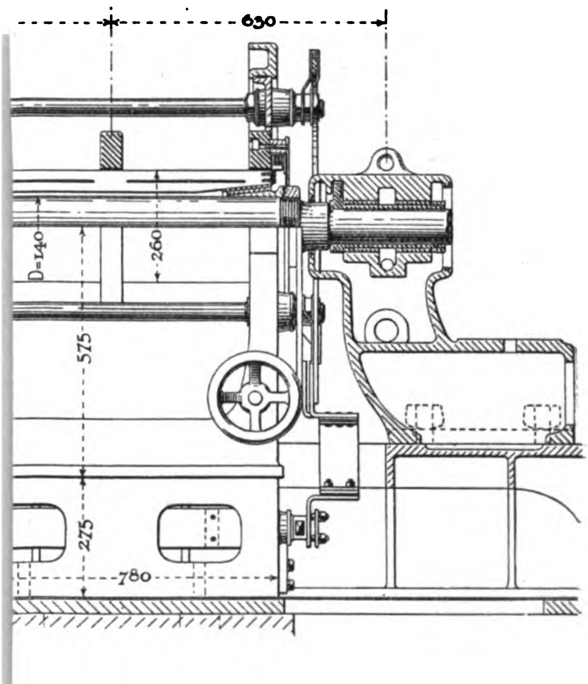

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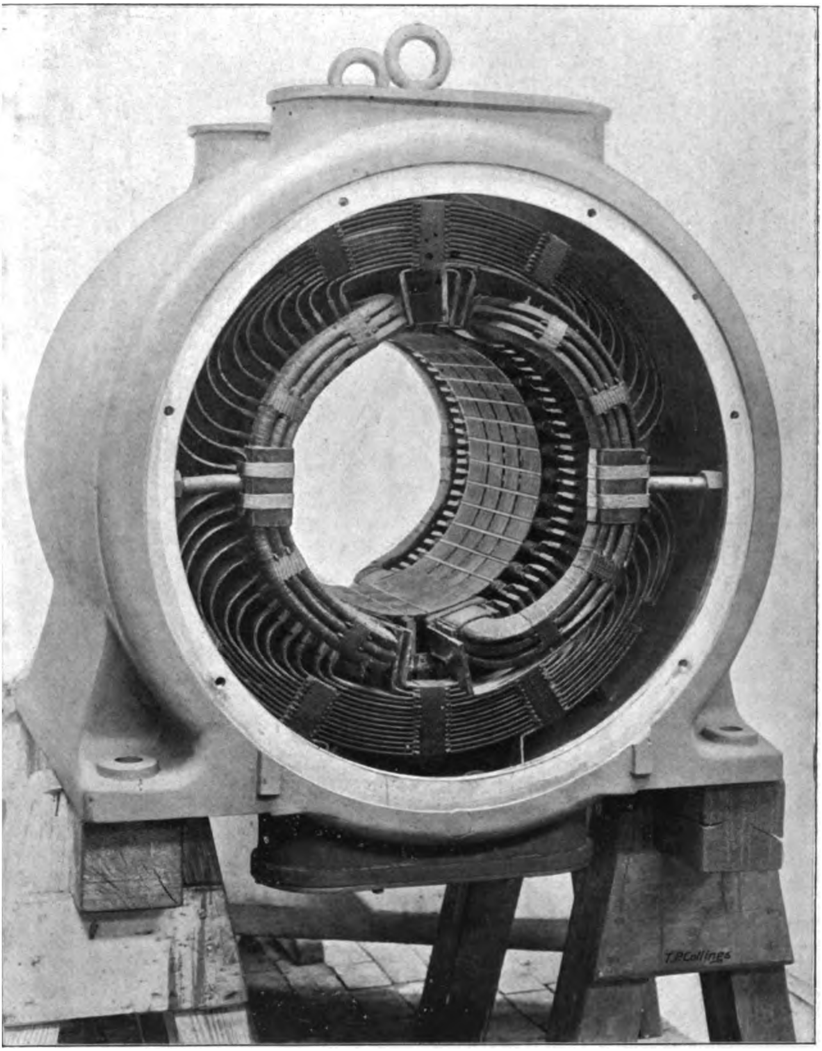

FIG. 26.—Field Magnet Frame (Wound) Turbo-Generator.

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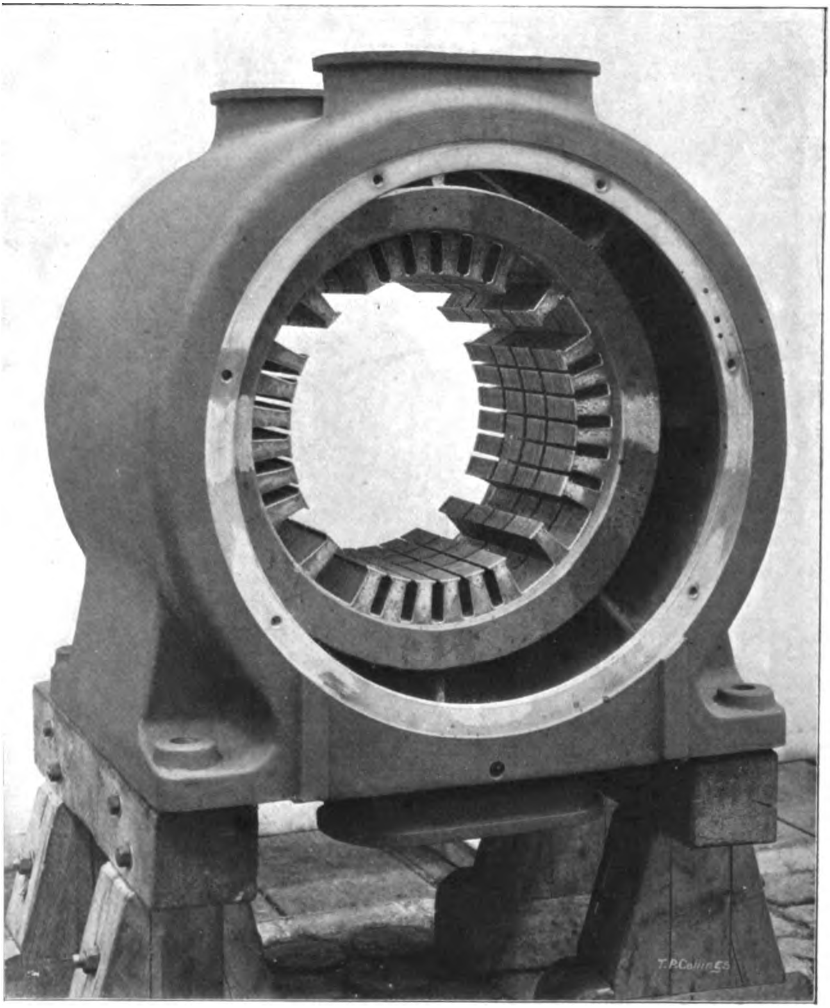

FIG. 27.—Field Magnet Frame (Unwound) Turbo-Generator.

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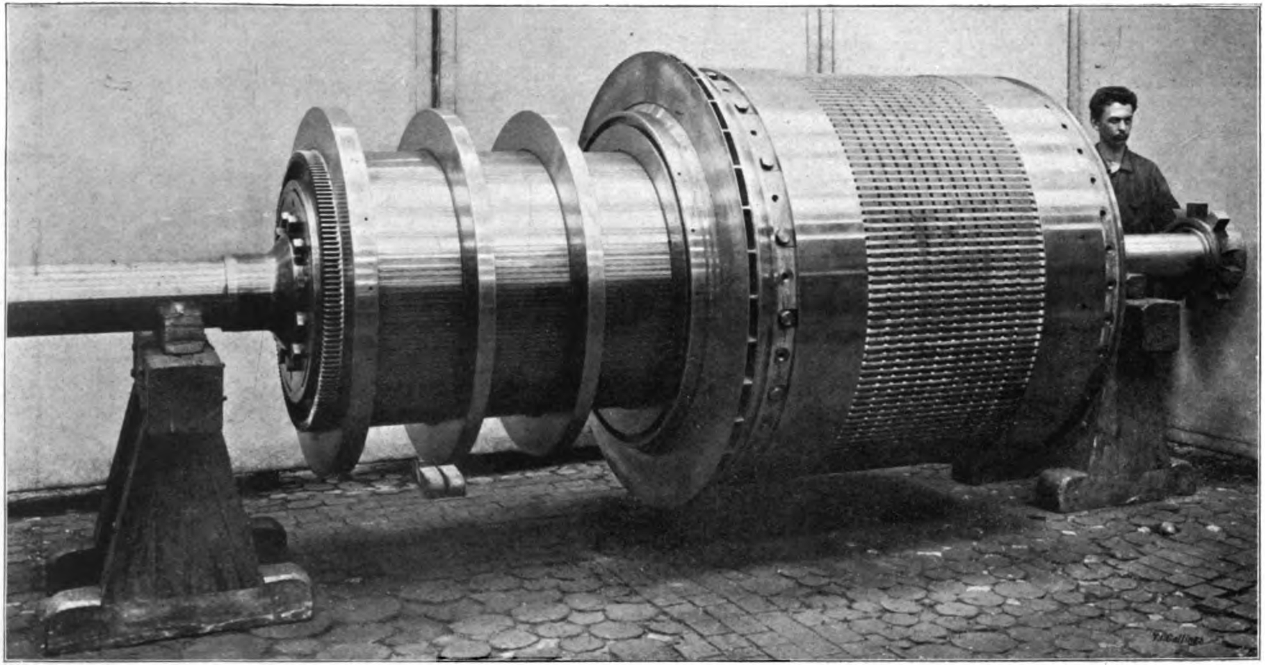

FIG. 28.—Armature Turbo-Generator.

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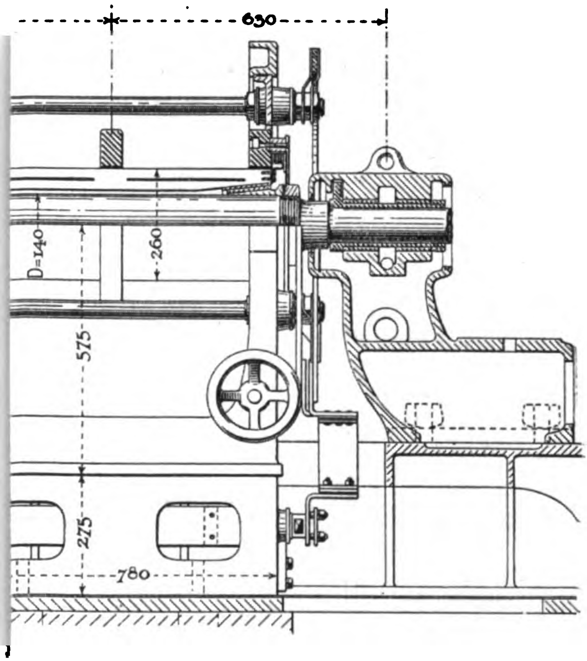

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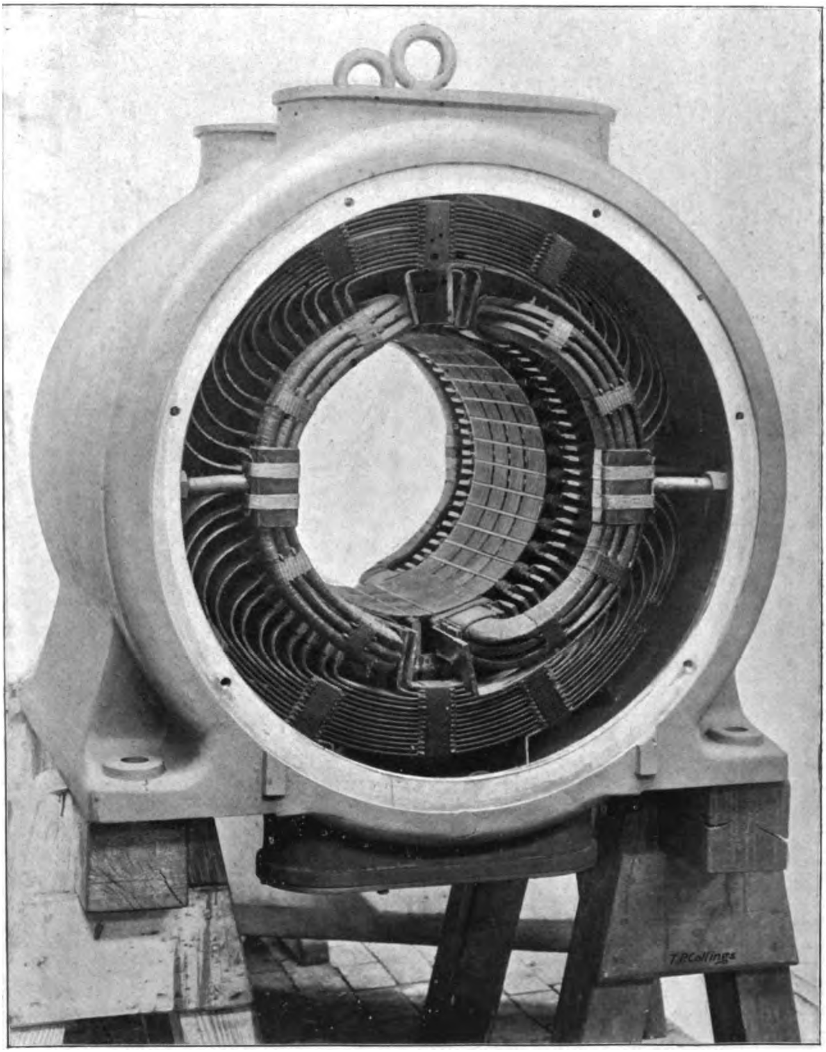

FIG. 26.—Field Magnet Frame (Wound) Turbo-Generator.

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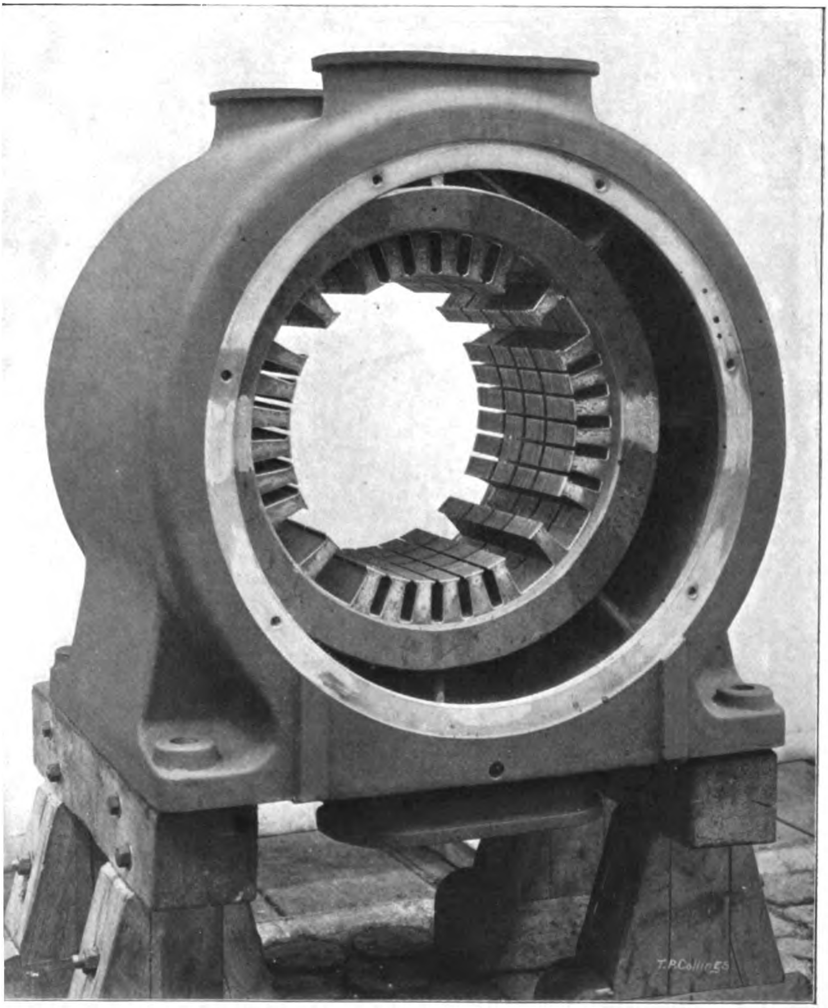

FIG. 27.—Field Magnet Frame (Unwound) Turbo-Generator.

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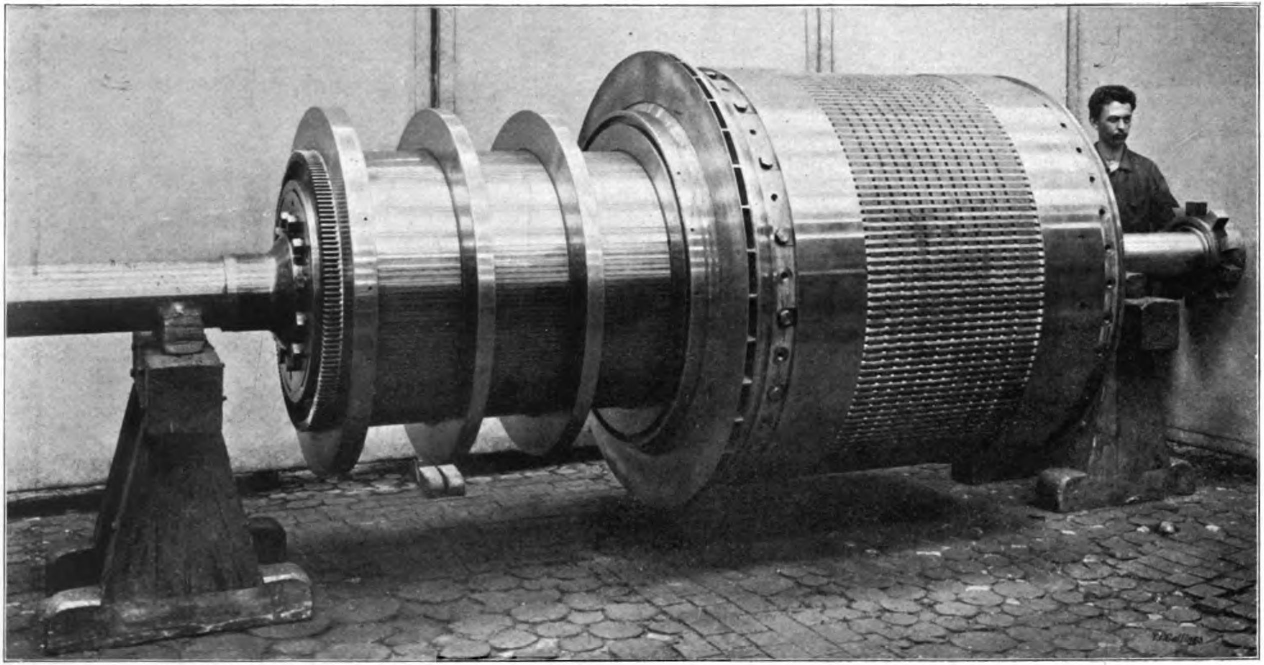

FIG. 28.—Armature Turbo-Generator.

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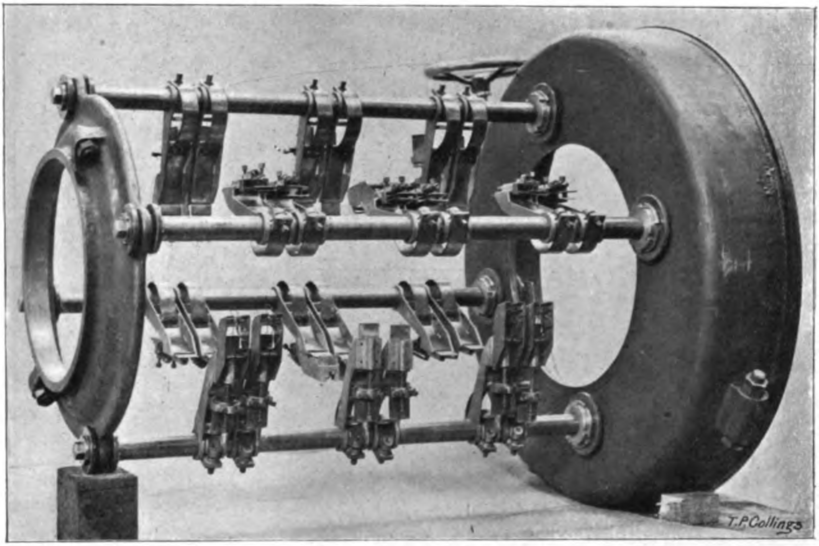

FIG. 29.—Brush Gear Turbo-Generator.

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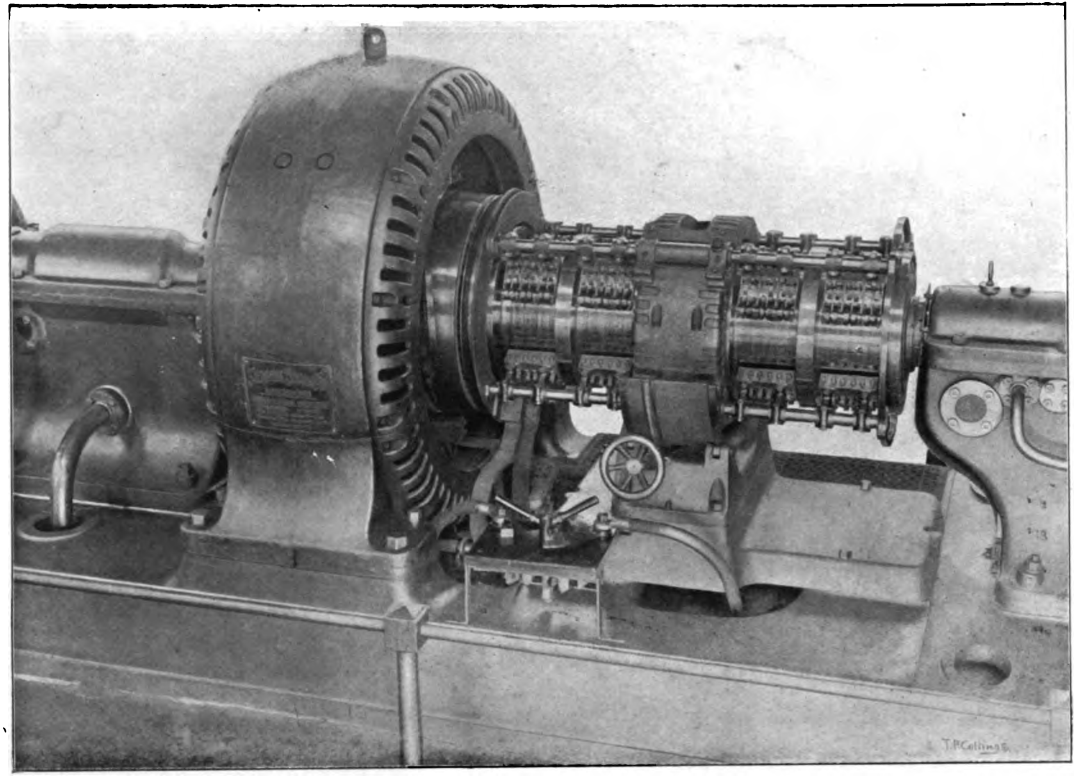

FIG. 30.—Turbo-Generator.

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A typical armature is given in Fig. 28. Special means are provided for ventilating the machines, as will be seen from the cooling fans fitted in some cases at both ends and in others at only one end of the armatures. The brush gear shown in Fig. 29 is of a special type consisting of two parts, one carbon and the other copper tipped to facilitate the easy collection of the current.

The ventilation system is as follows: Air is sucked in by the ventilators attached to the armature and passing also through the ducts is carried up through the field system and passes out at the ventilating opening shown in the top of the field frame.

Fig. 30 shows a photograph of a dynamo by Siemens Bros. & Co., the most noteworthy point being the commutator, which is of their special air cooled type, and is used when a large current has to be collected.

In conclusion the authors desire to thank the many firms who have so kindly supplied the photos, etc., given above, without which the paper could not have been carried through.

APPENDIX I.

Method for Calculating the Interpolar Air-gap Reluctance.

The calculated curve in Fig. 6 was arrived at by a method similar to that proposed by Messrs. Hawkins and Wightman * for the determination of the equivalent air-gap under the main pole. The method is, however, different in its application owing to the small number of teeth per pole.

The E.M.F. induced in the coil is the sum of the E.M.F.s induced in the two sides, and this again is proportional to the total flux cutting across either side. If the value is known of the flux entering the tooth preceding the conductor under consideration the E.M.F. induced can at once be determined, provided the width of the tooth and the surface speed are known. The ampere-turns on the interpole were known and the reluctance was obtained graphically, then

$$\text{E.M.F.} = \frac{\text{Tooth flux,}}{\text{Width of tooth in cm.}} \times \text{surface speed in cm. per sec.} \times \text{conductors in series.}$$

In calculating the reluctance, account was taken of the different reluctances of the teeth under the different poles as spoken of when discussing windings in Section III. The total reluctance from one pole to the next through the two teeth preceding the conductors was obtained and the flux calculated. This was carried out for the two paths which the flux takes from one pole to the two adjacent ones, and the total flux issuing from one pole was obtained by summing the two results.

In actual practice the approximate method given first in Section III.

* *Journal Institution of Electrical Engineers*, vol. 29, 1900, p. 436.

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will be found sufficiently accurate and considerably quicker than the above. For difficult cases where a more careful determination is required resort should be had to the second method.

APPENDIX II.

METHOD FOR EXPERIMENTALLY DETERMINING THE FLUX CURVE.

The curves of flux distribution shown in Fig. 1 were obtained by a method first brought to the notice of one of the authors by Dr. Breslauer of the Technische Hochschule, Charlottenburg. The test is carried out as follows:—

Two slip rings, A and B (Fig. 31), are mounted on the shaft of the motor to be tested, A being a continuous ring of metal, whilst B is an insulated disc with a copper contact brought out at one point of its periphery; they are connected to two adjacent segments of the com-

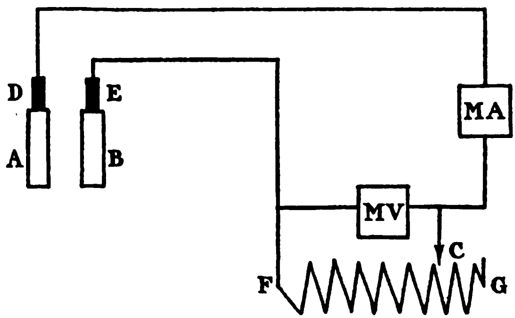

FIG. 31.—Diagram of Connections for Field Distribution Curve Test.

mutator. Brushes D and E bearing on these rings make contact with the slip ring A and the point B respectively at a given part of the armature circumference depending on the position of the brushes. F G is a resistance connected across the external supply mains, one end being joined to the brush E; a movable contact C makes connection through a milliameter M A to brush D, the millivoltmeter M V is put across F and C.

In taking a reading the pointer C is moved along F G until the drop across F C is equal to the voltage across D E; the milliammeter M A will then read zero, and the millivoltmeter M V will measure the voltage across D E. Readings are taken with the brushes in different positions round the commutator until the complete circumference has been traversed.

By plotting voltage against position of the brushes the curves shown in Fig. 11 were obtained. This voltage is the sum of the E.M.F.s in a complete loop of the armature as connection was made on two adjacent

segments of the commutator: account is thus taken of the averaging effect spoken of above. The advantage of this method is that no current is taken out or put into the armature, and the normal conditions of the motor are unaltered. The objection to it is the length of time required to take one curve, and during this period it is extremely difficult to keep the test conditions the same.

Discussion.

Mr. F. E. Ussing: The paper gives much useful information on interpoles, and the curves in Figs. 9, 10, 11, and 12 are very instructive. The authors use Dr. Breslauer's formula for reactance voltage, and rightly point out that the term in this formula which takes into account the reduction in magnetic reluctance due to the auxiliary pole being placed exactly over the coils undergoing commutation is not necessary for machines with solid pole pieces. I would go further, and say that it is not necessary at all. I made a few tests with a normal machine with laminated pole shoes, and found that as soon as the poles were excited the increase in reactance voltage of a coil situated directly under the centre of the pole as compared with a coil situated midway between the poles was very small. Even with very low saturations I do not believe that the increase in reactance voltage due to the interpoles would be more than 10 to 15 per cent. This paper brings again to the front the important question whether direct-current machine designs should be completely rearranged on the interpole basis or not? The authors seem to advocate the standardising of machines of outputs above 40 or 50 k.w. on the interpole basis, but consider the standardising of machines below this output as likely to be uneconomical. I am of almost the opposite opinion; I believe it is most rational in all cases to consider the interpole machines as a special line of machines. It would perhaps be possible in some degree to standardise the smaller machines on an interpole basis in so far as one would be able to use most of the mechanical parts of the normal machines for the interpole machines, and one could in many cases with advantage provide the 500-volt machines with interpoles; but for machines about 50 k.w. I believe that the standardising on an interpole basis is quite out of the question, due to the greatly varying working conditions for machines of greater outputs. Even with normal machines one can hardly standardise above 200 k.w., and I do not see that the authors of this paper have given any proof to the contrary. For instance, they state that the heating limit is the same for machines with and without interpoles. I have always found that the interpoles impair the ventilation considerably. Furthermore, they themselves state that a reduction in commutator copper for the interpole machine is to a certain extent more apparent than real. This, I think, could also be said of the gain in efficiency claimed by the authors for interpole machines; I find that generally the efficiency is about the same for interpole and for normal machines. I believe that interpoles have their Mr. Ussing.

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Mr. Ussing. own useful field, but I find that many firms have gone in for the interpole machines on far too general a scale. I should like to know how the authors justify the use of interpoles for a 200-k.w. 500–540-volt 400-r.p.m. machine, or still more for an 1,100-k.w. 630-volt 94-r.p.m. machine. At all events, sufficient data are not given in the paper to make this clear. I am of the opinion that all the known and possible improvements in direct-current dynamo design should be fully utilised before turning to the use of interpoles. Series-parallel windings with equalisers under the Arnold patent may in many cases prove useful. Several Continental firms are using these windings extensively and with good results, and I find the author's statement about this winding rather ambiguous. I should like here to draw attention to a new improvement in direct-current windings, namely, the use of equalisers between the various separate parallel windings of a multiple-circuit doubly-re-entrant duplex or multiplex winding. This patent is the invention of Mr. Franklin Punga. The arrangement is illustrated in a diagram on the wall. The normal multiple-circuit doubly re-entrant duplex or multiplex winding without equalisers can only be used to their full advantage when the voltage between the segments belonging to the different parallel windings are equally distributed, that is to say, the potential between segments 1 and 2 should be exactly half of the potential between segments 1 and 3; but without special means of bringing about this condition it is rather dangerous to use these windings, as it may happen that the potential is very unevenly distributed between the segments, and this would give rise to very great equalising losses over the brushes. The winding shown in the diagram on the wall is a multiple-circuit doubly re-entrant duplex winding; the full lines *u*, *v*, in Fig. I indicate one of the parallel windings, and the dotted lines *x*, *y*, indicate the other winding, the thick lines *m* at the bottom of the diagram denote the normal equaliser connections for the winding in full lines, and the thin lines at the top denote the normal equaliser connections for the winding in dotted lines. The corresponding equaliser rings of the two parallel windings are connected through the equalisers indicated by the lines *o* on the left of the diagram, and by means of these connections an equal division of potential between adjacent segments is ensured. The potential of point *e* lies midway between the potential of segments 2 and 4, the potential of segment 3 will therefore also be midway between 2 and 4. In the diagram the point *e*, which should be of the same potential as segment 3, is connected through two rings and the connection *o*, the complete equalising connection is denoted by the letters *a*, *b*, *o*, *c*, *d*, *e*.

We have tested this kind of winding with equalisers on an 1,800-ampere 40-volt machine at 540 r.p.m., and though the reactance voltage, considering the winding as a normal parallel winding, is about 2, the machine runs absolutely sparkless with copper brushes and the brushes in the neutral position. The firm with which I am connected has also several machines going through the shop with this winding, among others a 1,000-k.w. 230–270-volt 250-r.p.m. machine. For the latter machine

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the reactance voltage would, when the winding is considered as a normal parallel winding, be about 7, but on account of the equal potential distribution between the segments ensured by this invention the effective reactance voltage will only be about 3·5. We also find this winding useful for interpole machines, especially turbo-machines for low voltages. I believe that windings and improvements like those mentioned here should extend considerably the field for normal continuous-current machines, and at the same time should tend better to define the wide, but nevertheless limited, field of interpole machines. Mr. Ussing.

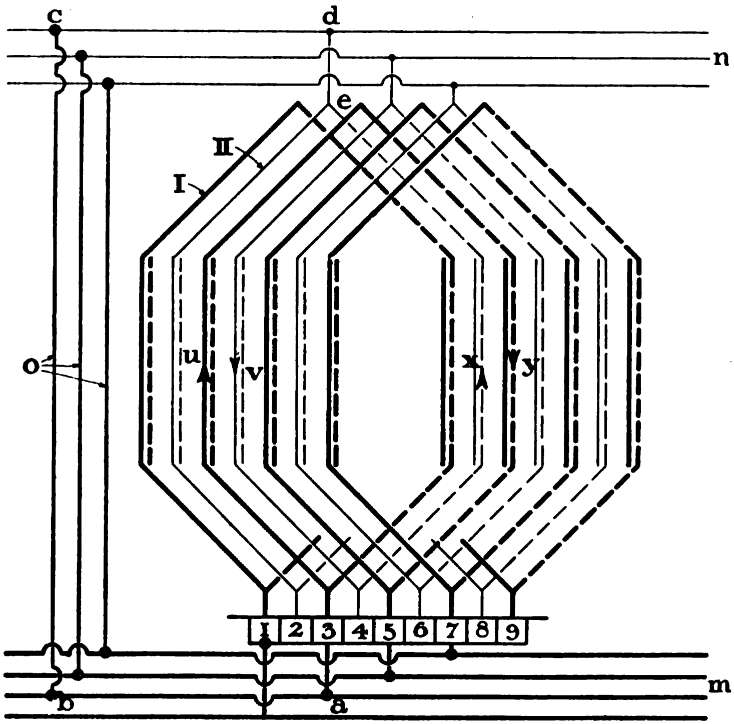

FIG. I.

Mr. A. G. ELLIS: The authors have given a good account of the several factors which are brought into prominence by the application of interpoles, but I do not think their conclusions may be regarded as perfectly general. The employment of interpoles has in itself been made by far too general a matter. The interpole has been revived principally by the commutating difficulties encountered in high-speed dynamos, but there has been a more or less general stampede away from its application to designs where the interpoles are the proper thing, to a general application to all types and sizes of machines more or less Mr. Ellis.

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Mr. Ellis. indiscriminately. Interpoles have a definite and legitimate field of application, but their application to cases where a good design can be obtained on ordinary lines is not justifiable. On page 572 it is stated that "the development of the interpole has led to a better mechanical design which ensures a more efficient ventilation and a lower works cost due to the greater saving in material." It would seem to be implied from this that the saving in material is a consequence of the more efficient ventilation, and that interpole machines have, as an inherent property, better ventilation. It should be remembered that the better mechanical designs and ventilating schemes are equally applicable to machines without interpoles. In fact, a modern non-interpole machine has decidedly better heat-dissipating facilities on account of the fact that the air circulation is not impeded by the interpoles. If one inspects either of the machines in Figs. 17, 18, and 19, it will be seen that the field system is practically a congested mass of copper and iron, through which it is very difficult for the air leaving the armature ducts to circulate, both the armature and field heating being thus affected. Then as to the "lower total works cost due to the greater saving in material," it should be noted that the interpole machine is essentially a "copper" machine, and the present high price of copper will have a marked influence on the total works cost. Further, although an interpole design may, in certain instances, show a slight total economy in material, there are the extra labour charges associated with the interpoles which tend to offset any such saving. The authors mention the question of labour charges on page 584 as "of considerable consequence," and partly on this account limit the employment of interpoles to machines of above 40 to 50 k.w. I do not consider the labour item to be so serious, especially in small machines, as all the machining necessary may be done at the same time as the machining for the main poles, the only other item being the winding of the interpoles. In fact, on page 595, the authors state that it is their own practice to cast the interpoles in with the yoke, so that the only labour required is to bore the pole-faces, which may be done at the same time as the main pole-faces, and wind the interpoles. In Figs. 1 and 2 are given curves for iron losses. The form of these curves and the relative results are fairly well known, but they would be more useful if the authors had plotted the watts per kilogram against the flux density, or if they would give us the total weight of the armature core and the normal flux density. With regard to temperature rise by taking into account the exposed surfaces marked in Fig. 3, the authors endeavour to estimate the temperature on a more rational basis, but from an examination of the values of the "constant" in Tables I. and II. it is questionable whether this method has any advantage over the ordinary method, which simply takes into account the armature air-gap surface over the windings. In the surfaces marked in Fig. 3 a difference should certainly be made for large and for small machines, as in the latter the stampings are mounted directly on the shaft and the internal cylindrical surface of the armature, even if it has

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ventilating tunnels, contributes only in a very small degree to the heat dissipation. The authors state that the value of the "constant" varies with the actual temperature rise, and consequently, in estimating by this method, one must know the temperature rise beforehand in order to choose a value of the "constant" for estimating that temperature rise. I have found that, for high-speed alternators, a useful surface on which to reckon the watts per square decimetre is the total external surface of the core, *i.e.*, the internal and external cylindrical surfaces and the two end surfaces of the core. In using such a rule for continuous-current armatures, one must consider whether the internal surface is of much use for heat dissipation, as noted above. On page 577 the authors call attention to the distorting effects of the armature in variable-speed machines when running at top speed with the weakest field, and the obtaining of low reactance voltage by use of large commutators with many segments, and the use of strong fields. These points cannot be too strongly emphasised, as there exists an erroneous impression that with interpoles to take care of the commutation, strong armatures, few segments, and high reactance voltages may be employed without trouble. Such procedure is in no way justified by interpole designs. A matter which becomes very prominent in wide-range variable-speed motors is that of flashing over at the commutator at top speed. A motor with a speed range of 4 : 1 or 5 : 1 may, at certain points on the commutator, have a voltage per segment several times the average voltage per segment, and there exists between certain points a potential much greater than the actual terminal voltage. Oelschlaeger has given some tests in the *Elektrotechnische Zeitschrift* of March 7th on a 500-volt 21-H.P. 200–875-r.p.m. motor. This motor had a voltage of over 800 volts existing at the commutator at the highest speed. The reason of this is the uneven distribution of potential caused by the much distorted field. The conditions are clearly shown by the diagrams in Figs. J to M, which are the results on a 50-H.P. 500-volt 200–1,000-r.p.m. motor which Mr. Hobart has had carried out and kindly placed at my disposal. Figs. J and K show the resultant flux distribution at 200 and 1,000 r.p.m. respectively, with the armature loaded. The dotted curve indicates the field flux at no load. Figs. L and M show the potential distribution around the commutator at these two speeds. At 1,000 r.p.m. there exists a voltage of about 1,100 volts. The flux curves in Figs. J and K also represent the curves for the volts per segment. The volts per segment reach a value of five times the average volts per segment. Mr. Ellis.

The interpoles themselves do not assist in overcoming the distortion. It appears that a distributed compensating winding is better in such cases, as the distortion would be much reduced and the flux curve would assume almost the shape of the dotted curve in Fig. K due to the main field. In the method of determining the dimensions of the interpoles and in the third term of the formula on page 578, the flux density in the interpole air-gap is not brought in, but the length of air-gap enters. Is this formula for a constant pole-face density which is contained in the numeral 6? On page 582 are mentioned values for the gap densities,

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Mr. Ellis. and if such a range of values is employed the saturation component of the interpole ampere is considerably affected. In the other formula,

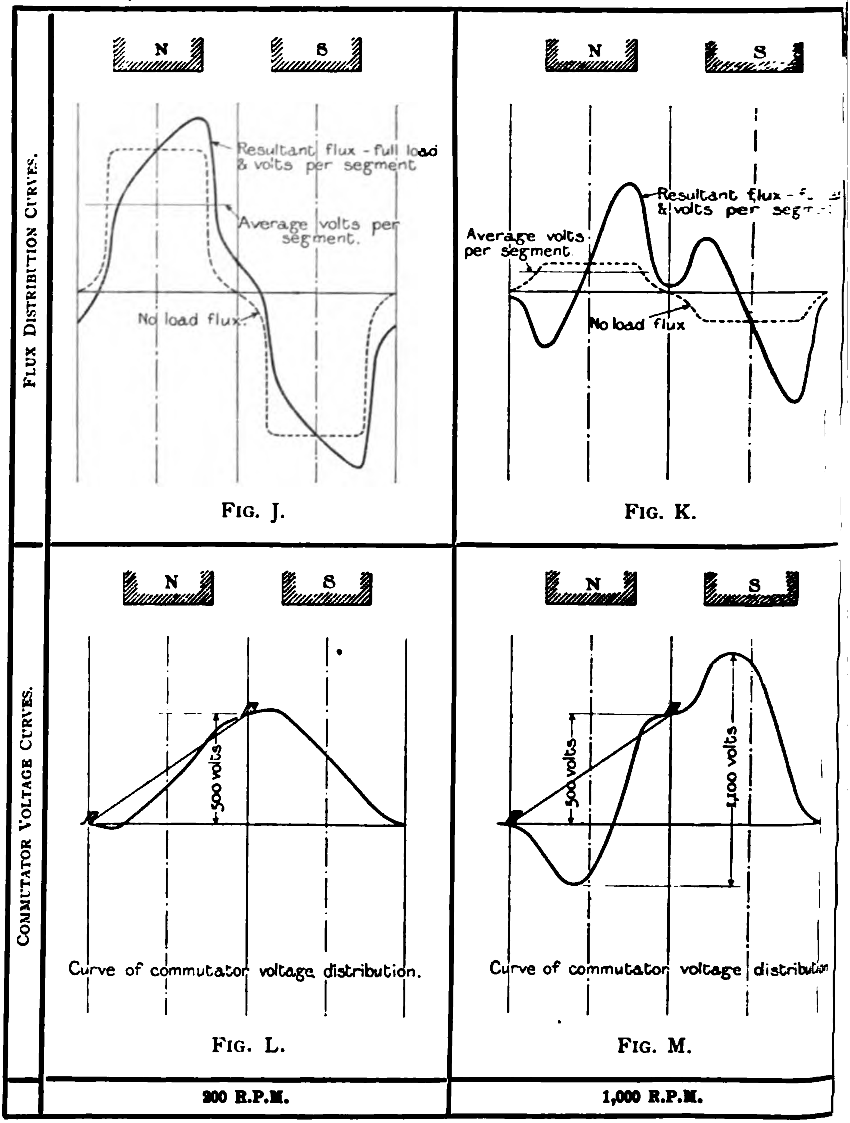

FIG. J. FIG. K.

FIG. L. FIG. M.

on page 579, there occurs a constant for which no value is given. Will the authors give us this value? It would have been clearer if they had taken an example and applied their formulæ to it. On page 583 it is

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noted that the interpole core should be made circular in section, which is quite correct. It is remarkable that the four typical examples given in Figs. 17, 18, 19, and 24 each have a rectangular pole extending the whole length of the armature. The shape of the interpole affects the shape of the main pole, and I do not quite follow the arguments on page 584 for a square main pole. I believe that the best use may be made of the space by employing circular main poles and circular interpoles set to the ends of the armature, as in Fig. 20. Of course this is not possible if the interpoles are very wide, as in Figs. 17, 18, 19, and 24, but I do not think such wide interpoles are required except in rare cases. The arrangement in Fig. 20 is much better than that in Fig. 17, and also from the point of view of cooling of the windings, reduced leakage, and shorter mean turns of copper, and it is worth having a rather larger diameter and pole-pitch to take advantage of it. Mr. Ellis.

On page 590 the authors state that the iron losses are less due to decreased tooth densities. I do not think this is the reason, as the tooth densities quoted by the authors on page 585 are about the average values. The iron losses may sometimes be slightly reduced in interpole designs by employing a smaller flux, and consequently a less weight of armature core. It is in some cases possible to improve slightly the shape of the efficiency curve for interpole machines by these means, but as to full load efficiency there is little to choose between the two types, and the advantage will generally be with the non-interpole type. It should also be remembered that in variable-speed motors the core losses are likely to be very large owing to the field distortion. Also in interpole machines there are the extra eddy-current losses in the interpole shoes.

The statement on page 592 regarding Figs. 18 and 19 calls for comment. It is said that "the main coils are now being wound on a part of the pole, the rest being left bare to permit of more room for the commutating coils." This is just the thing to encourage leakage. In the first place, there are wide interpoles which greatly increase the leakage, and then it is proposed to leave part of the main pole unwound, and that part nearest the pole-shoe, which is just the point where the coils should be placed to minimise the leakage. This trouble and the cramping of the winding spaces are due to a desire to reduce the armature diameter, and it would probably be wiser to be a little more liberal in the diameter and pole-pitch, when several of these difficulties would disappear. I do not see where the advantages lie in employing interpoles for such a rating as that in Fig. 19. A good design for this rating could be obtained without interpoles quite well, and at less expense even at a considerably higher speed than 94 r.p.m. Mr. Hobart has recently investigated designs of various ratings over a wide range of speed, and finds that it is not more economical nor advantageous to use interpoles for speeds below the following: 250 k.w. 250 volt 500 r.p.m., 500 k.w. 500 volt 500 r.p.m., 1,000 k.w. 1,000 volt 250 r.p.m.

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Mr. Glendenning.

Mr. S. E. GLENDENNING: Most of what I had to say has been well expressed by Mr. Ellis, and I will not labour the point further. There are, however, one or two points of design which I should like to mention. With regard to the winding for the commutating poles, two very interesting formulæ are given in the paper, the second of which will, I hope, never come into general use: life is too short. One always distrusts pure theory in a case like this where—when you have finished—you have to make a 20 per cent. correction for contingencies, and the more complicated the formula the more you distrust it. I hope, before things have gone much further, that the theory will be simplified. I have always used an approximate formula, which is simpler, and perhaps as accurate. With regard to the tabulation of test results in such a way as to make them available for future work, a method of plotting the figures, which I have used, may interest those present. I plot the ampere-turns needed for the auxiliary gap against the reactance voltage per bar at 1,000 ft. a minute, that is to say, against the reactance volts on each machine reduced down to a single bar at a common peripheral speed. This really gives an experimental characteristic of the auxiliary pole. For a given size of auxiliary pole, the limits on 1, 2, 3, or 4 turn windings agree very fairly when regarded in this way.

I quite agree with Mr. Ellis that round main poles are much better than rectangular, and the firm with which I am connected have adopted them for auxiliary pole generators. I believe this design makes a lighter and a rather cheaper machine than heavy flux machines such as are recommended by the authors.

With the introduction of new methods in design, a crop of new diseases has come. One mentioned in the paper is that of hunting. The only hunting I have come across has been due to the brushes being too backward so that the machine acted, due to the armature reaction and auxiliary pole flux, as if it were slightly negatively compounded, and pushing the brushes forwards cured the fault. Another trouble is a very undesirable addition to the English language which has been adopted by the authors of the paper, regardless of the fact that the preposition "inter" should carry with it some part of a verb signifying "rest in" or "motion to."

The authors state (page 572) that the constant for multiplying text-book eddy losses is about 10; I have found it generally about 7, varying with the design of the machine, but very fairly consistent with 4 ft. diameter armatures down to about 6 ins.

I am glad the authors do not advocate auxiliary poles on small machines, where their adoption is, I believe, largely due to fashion. On large machines the advantage is not as great as was originally claimed owing to considerations of design which there is not time to go into now. I do not wish to depreciate commutating poles—they are extremely useful under some circumstances—but it would be a great pity if, for the sake of fashion, they were to get fossilised into standard specifications, along with "best Indian mica" and "copper of 100 per cent. conductivity," and other equally meaningless expressions.

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Mr. Glendenning.

(*Communicated*): I mentioned a simple method of plotting test results of auxiliary poles. Fig. N may make my meaning clearer. The abscissæ represent the ampere-turns on the auxiliary poles, less those required for overcoming the armature, and for leakage; the ordinates show the corresponding values of—

$$\frac{\text{Limiting reactance volts}}{\text{Conductors between adjacent segments}} \times \frac{1{,}000}{\text{periph. speed}}.$$

The curve should be plotted (for each size of auxiliary pole) from tests on machines of fairly high reactance voltage, so as to eliminate the effect of natural commutation as far as possible. The total reactance voltage of a machine should not differ by more than 1 from that deduced from the curve, nor should it exceed, say, 15.

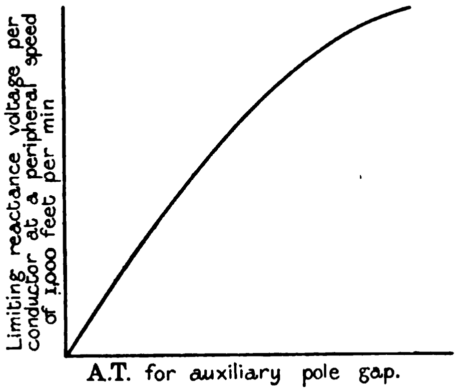

FIG. N.

Auxiliary poles are not recommended by the authors for small machines, but their limitations on larger sizes deserve, perhaps, more notice than was given in the paper. Take, for example, a generator of 150 k.w. or so at 400 revs., the temperature rise of which, as a normal machine, is about 55° or 60° F. By simply adding intermediate poles the output can be increased by about 15 per cent., but the cost has gone up 8 or 10 per cent., so that the net gain is small. If, now, we develop the design so as to make fuller use of the auxiliary poles, we find that every gain is partly (but not quite) neutralised by a corresponding disadvantage.

The reduction of the air-gap increases heating and distortion, as pointed out in the paper, and it is to be feared will lead to trouble, as time goes on, owing to the heavy magnetic pull of unbalanced fields. If we employ a stronger armature and "starve" the magnetic circuit the limit is quickly reached; as not only have the armature and field magnets to be made of larger diameter, but the number of ampere-turns needed on the auxiliary poles rapidly increases, forming the chief

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Mr. Glendenning.

limiting factor in the design. Deep coils are expensive to wind on a small core, while the alternatives of long pole-cores or many poles have obvious disadvantages, and in any case leakage becomes serious.

The use of fewer commutator sections and 2 or 3 turns per section instead of 1 or 2 is not always admissible, as it brings us over the limit of reactance voltage, if not of volts per section. In short, to get 10 per cent. more out of a given machine by modification of its design, we must make the commutating conditions with which the poles have to deal something like 40 per cent. more onerous. A moderate design on these lines has, however, its good points, and I cannot agree with the authors' use of a heavy flux machine of small diameter with square pole cores as an auxiliary pole dynamo. The chief objection is that there is not proper room for the intermediate poles with square main poles, even if there looks to be a fair amount of space on the drawing. Round poles, on the other hand, are bound to leave the auxiliary poles fairly accessible, even if nearly touching them, and we find that the ventilation is better with this design. The principal sphere of usefulness of auxiliary pole machines will no doubt be in designs for high speeds with good all-day efficiency, and for this purpose a fairly light field with low flux densities in the armature core makes the best arrangement, the necessary saturation in the case of a dynamo being obtained in the pole-cores.

It would, therefore, seem best to keep this in view in design, fixing beforehand a suitable number of ampere-turns on the auxiliary poles as the limit. There seems little to be gained by trying to force up the output of the armature much beyond that given by the formula: Watts per rev. $= d^2 l \times 0{\cdot}04$ (d and l being in inches), and advantage must be looked for rather in a saving of materials due to a low gap density and light frame than in a small armature.

My remarks regarding the word "interpole" seem to have been liable to misconstruction. My meaning may perhaps be more clearly expressed in general terms thus—the prefix "inter," in my opinion, includes the idea of place, state, or motion.

Dr. Pohl.

Dr. R. POHL (*communicated*): Having strongly advocated the use of interpoles, not only for variable speed motors, but also for most machines above, say, 40 H.P., I was pleased to see that the authors, in their clear and practical paper, arrive at very similar conclusions, and that they corroborate my views as to the question of wide *versus* narrow interpolar arc, as to the advantages derived from axially shortening the poles, the number of main and auxiliary poles employed, etc. There are one or two points, however, with regard to which I should like to express a somewhat different opinion.

When the reactance voltage is sufficiently small or compensated the ratio of ampere-turns for gap and teeth to armature ampere-turns under pole-arc is not negligible, but, generally, should not fall below 1, because, otherwise, the field, under the weakened pole-tip, will become reversed and cause greatly increased iron losses. It is this consideration, and not always the mechanical limit, which settles the length of the air-gap

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in interpole machines. The authors' Fig. 15, showing the length of the air-gap as function of the armature diameter, though fairly well in accordance with modern practice for 4-, 6-, and 8-pole machines respectively, should, therefore, be considered with reserve, as the length of the gap is very nearly inversely proportional to the number of poles, *ceteris paribus*. In regulation motors the reversal of the field under the weakened pole-tip is, of course, unavoidable, and the increase in the iron losses has to be duly taken into account. In regard to the permissible voltage per segment the authors do not state whether their figure, 20 to 25 volts, refers to the average or the maximum value. In any case, it appears to be low, as in my experience, even for turbo-generators, a maximum voltage of 40 volts per segment is permissible, whilst in ordinary machines even 50 to 60 volts can be dealt with, provided that in the general design of the armature and commutator due care is exercised. Dr. Pohl.

As to the number of interpoles, the authors state that this may be smaller than the number of main poles provided that the armature has a series winding. Theoretically it is obvious that for all kinds of windings the number of interpoles may be equal to one-half that of the main poles. In practice, however, the authors found that the sphere for machines with a reduced number of interpoles is very limited and their operation less reliable. From experiments carried out two years ago in the test-room of the Phœnix Dynamo Manufacturing Company, I can confirm these statements.

The interpolar arc is, in my opinion, primarily fixed by the width of the actual commutation zone—as part of the neutral zone—which should be covered with ample margin. The number of slot pitches under the arc is a consideration of secondary importance, though, in smaller machines, it must not altogether be lost sight of.

In conclusion, may I emphasise the authors' valuable hint that the most economical machine is not necessarily the one with the highest output coefficient. If the cost of a certain machine is plotted as a function of the value ampere bars per centimetre armature periphery the curve shows a minimum for a comparatively low value, and, furthermore, it is rather flat. It is advisable, therefore, to keep well below the minimum, whereby a machine with excellent commutating and cooling qualities is obtained. Mistakes are often made not only in employing interpoles in cases where they are unnecessary and merely a complication, but perhaps more often in excessively increasing the output coefficient, where they are justly adopted.

Mr. W. E. Robson (*communicated*): The paper is of value to electrical engineers generally, as showing what is actually being done at the present time by the manufacturers of direct-current electrical machines. It seems somewhat surprising that designers and manufacturers should have neglected the very old and well-known device of the commutating pole for so many years, though all the while they have been building dynamos and motors of excessive size and cost to insure satisfactory commutating qualities in cases where the heating Mr. Robson.

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Mr. Robson. limits were not overstepped for the same outputs on smaller sizes of machines. The advent of turbo machines cannot be accorded the credit for bringing in the use of interpoles, as turbo direct-current generators have been constructed by Parsons for upwards of fifteen years. I remember that the use of interpoles was mooted by the Brush Electrical Engineering Company for traction motors about seven years ago, and complete designs and drawings were got out, but the project lapsed. As the result of several years' experience in the construction, manufacture, and application of interpole machines, I think it probable that their greatest future will be as variable speed motors. Prior to their advent a direct variable speed electrical drive for certain classes of machinery was hardly feasible, for the cost of a variable speed shunt motor, even for a 3 to 1 range, was so much above the price of a standard shunt motor as to make it much cheaper to employ gearing. Further, in spite of the claims made for the variable speed motor it was not generally a sparklessly running machine at the high speeds. The interpole motor for this class of work fills the bill very completely, and it is possible to get motors with a 6 to 1 speed range by shunt field regulation which will operate completely without sparking and stand heavy momentary overloads at the top speed.

This class of machinery, including several types of machine tools, which demands a variable speed drive with constant horse-power is very large, but I have also found the interpole motor misapplied for drives where the horse-power demand greatly increases with the speed. In these latter cases trouble ensued as a matter of course. The variable speed motor can, as a rule, give slightly greater horse-power at the high speeds continuously, owing to the heating limit being then only reached with heavier current.

Taking, however, the case of constant speed dynamos, the question as to whether the interpole type will displace the present general form will be decided mostly on the question of works cost. Competition is now exceedingly keen, and many firms are glad to accept orders at prices which preclude the possibility of supplying anything but the cheapest article that will meet the specification. The fact that constant-speed dynamos with interpoles are frequently supplied shows that in these cases the manufacturer is convinced that it is cheaper to adopt the interpole type than to face the cost of constructing a normal machine of good commutating qualities. Prior to the use of interpoles the output of even 500-volt dynamos in many cases was limited by sparking, and there was no serious attempt, therefore, to improve ventilation. But now, in these cases, if interpoles are used, the heating may reach the limit, and to enable a small size of frame and armature to be used greater attention is given to the ventilation, with the result that in many cases a direct saving occurs, or more generally a lower price can be quoted and the order secured.

As an actual example from practice, one size of dynamo has a normal rating of 150 k.w., 390 r.p.m., 500 volts, and the next size

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larger standard machine 220 k.w., 365 r.p.m., 500 volts. The price of the second machine is 30 per cent. greater than the first one. Each output is limited by sparking. A quotation is required for a machine to develop 200 k.w. at 380 r.p.m. on 500 volts. If the quotation is based on the second machine the order will probably be lost on the price, while the first machine would be rejected on test. Here it becomes a simple matter to quote for the first machine fitted with interpoles if the temperature rise is fairly safe, for the extra cost of these, including copper and all labour, will not exceed 15 per cent. If the heating limit, however, is nearly reached on the normal machine careful attention is given to the design and works cost, as the disposition of main and auxiliary fields will increase the heating, while providing extra ventilation may entail serious alterations to the standard construction. Mr. Robson.

I consider it very improbable that the interpole machine will become the standard construction for constant speed dynamos unless radical departures are made in ventilation with corresponding reductions in commercial efficiencies, and the interpole machine will be used for providing intermediate sizes to maker's standard list ratings. This is the more probable as we see that the commutating pole should vary in size with the output requirement.

I cannot see that the claim for standardised interpole dynamos is justified. The saving in cost due to lessened copper on the main poles due to smaller air-gaps will be much more than offset in most cases by the extra labour and material costs of interpoles and their windings. It may be noted as bearing on the interpole problem and the permissible heating that it is fairly general practice with some firms to risk exceeding their own guaranteed temperature rises, especially if they have reason to believe that there will be no keen supervision on test. As regards the construction, owing partly to inherently worse ventilation on interpole machines, the possible reduction of armature diameters and increase of core length soon reaches a limit. This is shown also in the paper, where the authors advise tooth density not exceeding 21,000 lines for ordinary type machines and also state that 19,500 to 20,500 are the lowest densities advisable for interpole types.

The increased length and reduced diameter does not mean a better mechanical design although it may in some cases very slightly reduce cost, for the shorter the armature is between the bearings the better for the machine. A reduction in commutator sizes does certainly take place in many instances, as softer brushes can be used, but as good conducting brushes of excellent commutating qualities can now be obtained, this reduction in size may often be made on ordinary machines. I do not believe that the number of segments in use will be greatly reduced, as the trouble of flashing over by reason of extra high voltages between segments has been proved to be a very real one, and the interpole without extra compensating windings of the Ryan type does not remove this fault but rather accentuates it. The fact of

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Mr. Robson. the commutator diameters being smaller does not necessarily mean a better mechanical design or a cheaper one, for the accompanying increase in length makes the commutator inherently more difficult to construct. In small machines especially a generous diameter is preferable as affording greater scope for secure mechanical tightening. The cooling surfaces taken into account by the authors in determining their constants for temperature rise are of interest, but the method used in the case of field coils is open to criticism. In most machines there is a clear layer of stagnant air between the inner surface and the pole, for the air cannot escape freely at the top, owing to the magnet frame. The layer of presspahn, red rope paper, etc., on the inner side of coil is also prejudicial to effective conduction or radiation. The curves given having similar characteristics to those of armature curves, show that the air thrown off by the armature has an effect in cooling the field coils, and this air can only come in contact with the outer surfaces neglecting the ends near the frame.

In the case of armatures the greatest amount of air comes in at the back end of the machine, comparatively little being sucked in at the commutator end. The parts of armature iron surfaces nearer the commutator end cannot therefore have equal value with the ventilating duct surfaces and armature external surface. The heating is in great part controlled by the quantity and the velocity of the air passed through the ducts, and this is dependent on the areas of inlets and outlets, the absence of throttling and the peripheral speed of the armature. As regards sparking limits, at the present time there is probably no better method of determining reactance voltage than that quoted by the authors, and which takes as its basis Hobart's determination of the number of lines of force created in the embedded and free lengths of the winding under commutation. Depending as it does upon the supposition of current change in sine-wave form, it is necessarily only approximate, but probably no two oscillograph records of a coil under commutation would show the same form of wave, and it forms a good practical method. The relative efficiencies of interpole and ordinary type machines are likely to remain more or less obscure as there is a dearth of data of machines for identical conditions. It would appear that the efficiency of the interpole machine is likely to be higher than that of the ordinary dynamo at light loads, but for fuller loads the position would be reversed owing to increased losses caused by field distortion, while the additional loss in the commutating pole coils comes in also. It is a great pity that the practice of measuring field-coil temperature rise by thermometer should still obtain so generally, and from the purchaser's point of view it would be much better to insist on the rise being determined from the increase of resistance. From the point of view of satisfactory operation the ordinary type of machine, if it fulfils the specified working conditions, is inherently a better machine than the interpole machine, as the latter will not work quite satisfactorily in parallel with other machines, unless very great care is given to the setting of the brushes.

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Mr. Scott. Mr. W. H. SCOTT (*communicated*): I have read with very great interest the paper on "Interpole Design." I would point out, however, that the generalisation in the last paragraph on page 577 that the difficulty of getting big speed variations increases as the voltage increases, is not correct. There are a certain horse-power and speed for each voltage at which the best commutating conditions can be obtained. This, I believe, has been pointed out by Mr. Hobart. Horse-power multiplied by speed represents, of course, the size of the machine, and for a given size the commutating conditions become less favourable at both higher voltages and lower voltages. I happen to be able to give a very instructive example of this from my own experience. My firm has made a very considerable number of 40-B.H.P. 6-pole motors with a speed variation of 4 to 1 for newspaper printing press work. We made seven of these to run on a 400-volt circuit about four years ago. They run at about 500 revs. per minute at top speed, down to about 120 revs. by flux variation; and they have been running some eight hours a day on very varying load, and often at an overload, and often 10 per cent. above their rated speed, for some three and a half years, without in any one case having had the commutators touched except in the way of cleaning, so that the commutating conditions (they are without interpoles) are as perfect as they need be. They have 395 sections in the commutator with single turn wave-winding. When we have to make similar machines for 200 volts we have to use interpoles, because our experiments show that we should not get good commutation with half the number of sections in this case, and duplex winding, we find, does not give the best results. Three hundred and ninety-five sections are about as many as can be conveniently used for a machine of this size; so that we have here a concrete example of the fact that for a certain voltage the best commutating conditions come with a machine of a certain size, and that with higher and also lower voltages the commutating conditions possible for the same speed would not be as good. Interpoles increase the range and make good commutation possible, where, without them, it would have been very difficult to obtain.

Mr. Page. Mr. F. H. PAGE (*in reply*): The general question as to whether interpole machines should be considered as a special or as a standard line of machines has already been discussed in the paper. There it was pointed out that, apart from the question of standardisation, the advantages in favour of their use are not so great with the smaller sizes as with large machines; even in these sizes the adoption of an interpolar construction by no means entails the rigid standardisation of all parts of the machine, which, as Mr. Ussing points out, is hardly possible with ordinary types above 200 k.w. It will, however, be found most economical for the usual class of machine above the limits of size given in the paper, to employ interpoles for the standard machine.

The advantages gained are well illustrated by the example given by Mr. Robson of a 150-k.w. machine which has its rating increased to

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Mr. Page. 200 k.w., and I do not think that he can require further justification for the use of interpoles on standard machines. In general one finds that the saving in copper on the main fields due to the use of the smaller air-gap and decreased allowance for reaction ampere-turns, more than offset the increased labour costs. This, in conjunction with the simpler commutator construction owing to a smaller number of segments being used, would quite justify the designs shown of Figs. 18 and 19. I regret that I have no further data of these machines to make the point more clear. It will not pay to reduce the air-gap too much, the figures given in Fig. 15 being fairly average practice; but it is certainly possible to effect a big saving by this means without incurring the increased heating and distortion, and the heavy magnetic pull of unbalanced fields spoken of by Mr. Glendenning.

The "heavy flux" machine has the advantage of smaller labour cost owing to the mechanical parts being small, and will on this score come out a good deal cheaper than the light field machine advocated by Mr. Glendenning. In the latter class one has practically the same weight of copper—the most expensive item—as with the former type; the only saving is in the iron, and this is not comparable with the decrease in the rating. Lack of room for the field winding is not necessarily a characteristic of the heavy flux machine; it is quite obvious that with the same cross-sectional area and length of pole there will be more room with a rectangular shape owing to its filling up less of the interpolar space. It only remains, then, to increase the section until there is no room wasted, but sufficient space is left for the interpole and its exciting coil.

The ventilation of interpole machines has attracted a good deal of attention, and has been touched on by several speakers in the discussion. The heating limits are, as stated in the paper, the same for all machines; by this it must be understood that the same amount of heat can be dissipated from unit surface, provided, of course, that the air has free access to that part. With interpole machines, where the sparking limit has been considerably extended, special devices have had to be employed to ensure that the air was able to circulate through the machine; in the development of the new methods of ventilation benefit has accrued not only to the special type under consideration but also to the ordinary series.

In calculating the temperature rise, Mr. Ellis rightly points out that it is no use considering the inner surface of the armature discs unless there is a circulation of air through the ducts. The same remark holds good for any other part of the surface, Fig. 3 showing the maximum surface which has been taken into account. If, for any reason, either part is closed up so as to prevent radiation, that part must perforce be neglected. I cannot agree with Mr. Robson that the inside surface of the coils do not radiate heat, for it will often be found that the iron conducts away the heat as well or often better than the air can dissipate it by radiation and convection. In considering armature heating, especially with large machines, one generally finds the

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greatest draught at the commutator end, owing to the fan action of the lugs. The cooling effect is therefore very often exactly the opposite to that mentioned by Mr. Robson. Mr. Page.

Figs. 18 and 19 are interesting as showing the extreme limits of interpole coil design with a view to minimising leakage. The best results would be obtained by employing a winding more like Fig. 17. It is inadvisable to taper the interpole coils, or sparking troubles will follow owing to leakage; on the other hand, a construction such as Fig. 19 will lead to expensive shunt coils.

Mr. Ussing is quite right in stating that the efficiency is about the same for interpole and non-interpole machines, provided he is considering the full-load point; but, as will be seen from Fig. 16—test curves of two similar-sized generators—the interpole machine has a decided advantage at light loads owing to its smaller constant loss.

The winding shown by Mr. Ussing—due to Mr. Franklin Punga—would be useful for low-voltage machines, where it is sometimes most difficult to find a suitable scheme, and would be most applicable to low-voltage machines of large size. For the ordinary machine of, say, 500 to 550 volts it would hardly supersede or be a substitute for an interpolar design.*

The curves shown by Mr. Ellis are very instructive, and serve to show most clearly the bad results one can obtain if the interpoles are not carefully designed. The figure of 20 to 25 volts per segment is the average value, and not maximum, as given by Dr. Pohl; it is, perhaps, a good deal on the safe side, but is a fairly good working figure, especially when some consulting engineers refuse a machine with a higher value than 12.

The formula due to Dr. Breslauer for the calculation of the interpole ampere-turns is true for any flux density, and Mr. Ellis will find the proof and the meaning of the coefficient 6 if he refers to the reference given in the paper.

The constant in the second formula is the same as the part included in the large bracket in Prenzlin's first formula. This part is constant for any given size of machine and slots, and once calculated it is easy to determine very quickly the reactance voltage for a different winding, speed, output, &c. It has the advantage that it is founded on a rational basis, and has been experimentally verified by experience.

Mr. Scott has taken exception to the remark that the difficulty of obtaining a good variable-speed motor without interpoles increases with the voltage, and gives an instance to bear out his remarks. One is, however, generally faced by the opposite problem, namely, having a 230-volt motor operating successfully to modify it so as to obtain sparkless commutation on 500 volts; usually it is impossible either to

* Series-parallel windings are most useful for large machines, especially in the cases given in the paper on page 588. In 4-pole designs it is better to employ a parallel winding in preference to a duplex, and with 6 poles a duplex winding should be avoided if possible. One finds that both the efficiency is impaired and the heating increased owing to large currents circulating between the two windings, a fault that is by no means rectified in small machines by equalising connections.

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Mr. Page.

employ double the number of commutator segments or turns per segment. A larger size machine has to be used, with a corresponding increase in price. When the choice of a suitable armature winding is being considered it will sometimes prove more difficult to work with lower voltages, but in general the difficulties are not nearly so great as with higher pressures.

The President.

The PRESIDENT : I will now ask you to accord the authors a hearty vote of thanks for their paper.

The resolution was carried by acclamation.

The following paper was then read and discussed :—

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HOT-WIRE WATTMETERS AND OSCILLOGRAPHS.

By J. T. IRWIN, Associate Member.

(Paper read May 23, 1907.)

The working of an ordinary hot-wire ammeter or voltmeter is well known. The commonest type is that shown in Fig. 1, in which a current passes through the wire A, B, C proportional to the current to be measured. The tension on the wire is sufficient to keep the two portions A B and B C comparatively straight. At B there is a wire or filament B E, which in turn is pulled back at the centre by the flat spring F G acting by means of the silk fibre G D. This silk fibre passes round a pulley P. The pull of the flat spring keeps the wire A C in tension, and if A C is heated and expands any increase of length in A C will allow the spring F G to move back and the pulley P will rotate.

The disadvantages of this instrument are :—

(*a*) The zero is not very constant owing to the wire having to be heated to a comparatively high temperature, say 100° C., while under tension; the result is a certain fatigue, which may prevent the needle from going back to its original position.

(*b*) The frame supporting the pillars which carry the wire A C owing to its larger mass will not attain to any normal temperature as quickly as the wire, and this may introduce uncertainty into the reading unless some means of compensation is provided in the instrument.

For ascending readings this may be an advantage, as the wire creeps slowly to its final position. During the same time the frame is slowly heating, which tends to reduce the reading, and therefore these two creeps may neutralise each other. The final result depends on which of the two has the larger effect. On descending curves these effects are reversed, but they again tend to neutralise each other. The error due to the above causes is always greater near zero, as the difference in temperature at high value on the scale is so large that any small variation of the frame from the normal does not make much difference to the reading, and of course the creep is proportionally less. Errors may also be introduced in this type of instrument by friction, by a gradual stretching of the wire, by a change in the resistance of the wire, or in its emissivity of heat, or by a change in the strength of the controlling spring. To minimise the zero creep, it is necessary (1) to make the tension on the wires small, and (2) to make the

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instrument independent of changes in the normal temperature and of the strength of the spring. The rate of heating of the wire, that is, the rate at which heat is being generated in the wire, is of course proportional to the square of the current flowing through it, and this means that when the current is small the readings are near together, in addition to being very uncertain. At the high readings the scale is open, and at these points the increase of deflection is nearly proportional to the increase of the current.

Up to the present, polarised hot-wire instruments have not been used, and herein the author describes a new type invented by him and some of the uses to which it can be applied.

In Fig. 2, C D and E F are two wires or strips of the same size; one pole of a battery B_1 is applied to D E, and the other pole of the battery is connected through two resistances R_1 R_1 to C and F. If the resistance of C D is equal to E F $= r$ (say), then there will be a current b flowing in each wire. If another current a from any other source is sent from

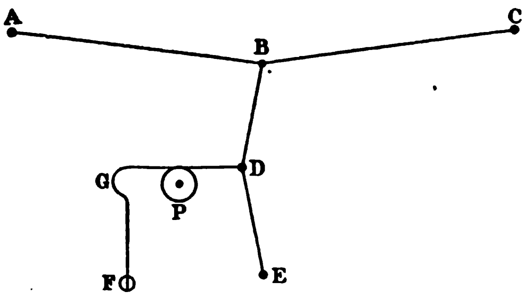

FIG. 1.

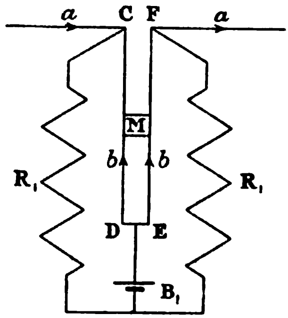

FIG. 2.

C to F through both the wires in series, the whole current a can be assumed to pass through the strips C D, E F owing to the resistances R_1, R_1 being large compared with the resistance of the strips, then the rate of heating in the right-hand wire will be $(a + b)^2 r$, and the rate of heating in the left-hand wire will be $(a - b)^2 r$. The difference in the rate of heating will be equal to $4\,a\,b\,r$. In any case the difference in the rates of heating is proportional to $4\,a\,b\,r$. Therefore if b and r are constant, the difference in the rates at which energy is given to the two strips is proportional to the current a, and if the current a reverses in sign, the difference will reverse in sign. If the wires C D and F E are each drawn back with equal and constant tension at their middle point, then a small mirror M placed across the two wires will be deflected through a certain angle proportional to the difference in temperature between the two wires, and this difference in temperature is proportional to $4\,a\,b\,r$ if the current a remain constant for some time; therefore one has a polarised instrument in which the deflection for small angles is practically proportional to the current.

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Although it might seem an easy matter to arrange to draw back the two wires with equal and constant tension, it is difficult when one considers that the movement in some particular instruments may be of the order of $\frac{1}{10000}$th of an inch. It is also necessary that the initial sag of the two wires should be the same, so that the sensibility shall be the same. The author spent some considerable time in trying to arrange two springs to draw the two wires back or push them forward with equal tension, and although he could get the deflection on each side equal to within about 10 per cent., this method was abandoned in favour of a better arrangement shown in Fig. 3. The wires C D and C F in Fig. 2, instead of being pulled back at their middle point, pass over independent and insulated pulleys P, P′ and return almost parallel to each other and

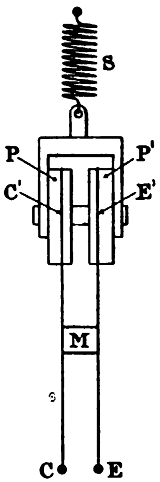

FIG. 3.

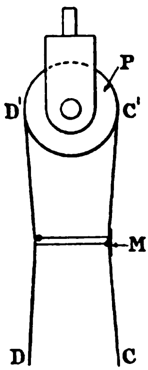

FIG. 4.

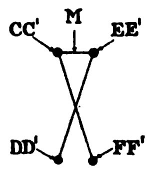

FIG. 5.

to their outgoing length as shown in Fig. 4, where the wire C C′D′D corresponds to the wire C D in Fig. 2. A similar wire E E′F′F will pass over the pulley P′; these two systems of wires are tied together diagonally, that is, the wire C C′ is tied at its middle point to the middle of the wire F′F, and the wire E E′ is tied back at its middle point to the middle of D′D. This is shown in Fig. 5. Now as the current passing through the wire C C′ is the same as that passing through D′D, if they are of the same length and of the same size, the expansion of each wire will be the same since the rate of losing heat is the same. The pulley P will not rotate and will only serve to insure that there is equal tension on each wire. The pulleys P, P′ are drawn up by the spring S. If there is no current passing through C C′D′D or E E′F′F, and if the wires are exactly similar at the same temperature, then the sag of the wires C C′, D′D, E E′, and F′F will be equal in each case. If a current

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is sent through the four portions, in series, then there will be an increase in length in all four wires, but there will be no deflection of the mirror. If the wire CC′D′D is heated it will sag more than the wire EF′F′F, and therefore the mirror will be tilted by an amount depending on the difference in the rates of heating in the two wires. This is very approximately correct for this type of instrument. Fig. 6 shows the curve connecting deflection with current passed through

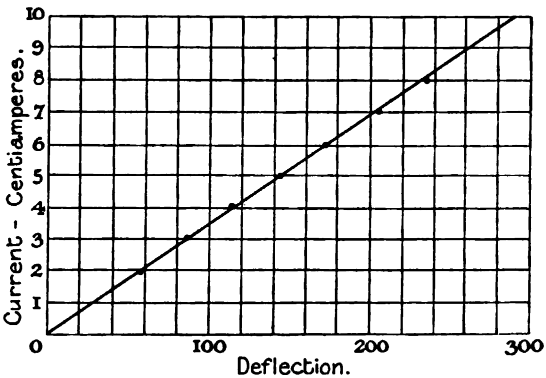

FIG. 6.

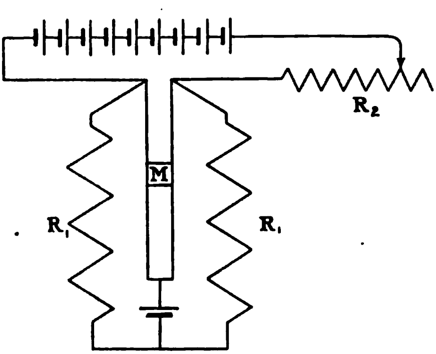

FIG. 7.

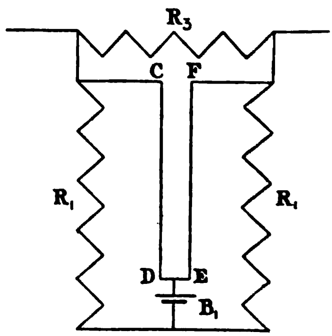

FIG. 8.

the two strips in series, when another constant current is sent through the two strips or wires in parallel as shown in Fig. 7. It will be seen that it is very nearly a straight line, any deviation from the straight line law being almost within the limits of experimental error.

The only objection to the instrument used in this way is that it requires a constant exciting current, and this would be a drawback to its general use. It could be used as an ammeter, voltmeter, or ballistic coulombmeter. Used as an ammeter, the main current or a current proportional to it would pass through the two strips in series, and a

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continuous current would be sent through the two strips in parallel as shown in Fig. 8. The instrument could only be used for continuous-current measurement. The chief advantage it would have over the same instrument used as an ordinary hot-wire ammeter (that is, by passing the current through one wire only and putting no exciting current on) is that one could read small currents with greater accuracy as the deflection would be proportional to the current. Used as a voltmeter the two strips in series will be connected in series with a suitable resistance and put across the two points between which it is required to measure the P.D.

There is a special case however where the instrument described has many advantages, namely, where it is required to measure the instantaneous voltage across two points or the instantaneous current flowing in a circuit. Suppose one wishes to measure the P.D. at every instant between two points A B (Fig. 9). The instrument C D E F is placed in series with a non-inductive resistance R_4. If the difference

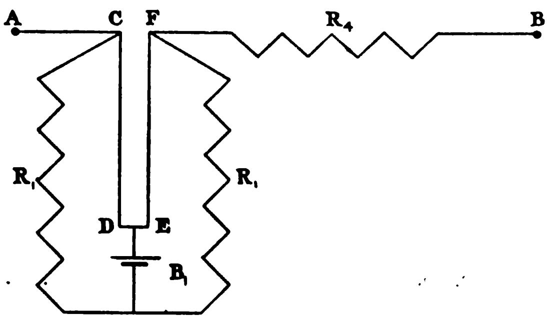

FIG. 9.

of potential across A B varies very slowly the deflection of the instrument will be practically proportional to the P.D. at every instant. If the rate of change of P.D. across A B is rapid, the heat capacity of the wires will prevent the difference in temperature of the two wires being proportional to the actual difference of potential. The rate of change which the instrument will follow with any given degree of accuracy depends on the ratio of the quantity of heat stored in the wires for a given temperature rise to the increased rate of loss of heat for the same temperature rise. The smaller this ratio is, the quicker the instrument attains a constant temperature after a given current is switched on. The ratio can be made smaller by immersing the wires and mirror in oil, which enormously increases the rate of cooling, making it six to nine times the rate of cooling in air. But even by this method the rate of change the instrument could indicate accurately is so slow that it would be impossible to use it for frequencies much above 5 per second. To make the instrument practical for ordinary frequencies the resistance R_4 in Fig. 9 is shunted by a condenser K as

shown in Fig. 10. The resistance of the instrument itself is low compared with the resistance R_4, being about $\frac{1}{100}$th of it for a R.M.S. voltage of 100 across A B. In this case there is a current flowing through the instrument at any instant proportional to the difference of potential across A B, plus a current proportional to the rate at which the potential across A B is varying, this last current flowing into the condenser. Suppose the curve in Fig. 11 shows how the P.D. across A B varies with reference to time. At any time t, the voltage is v, and there is a current flowing from A to B proportional to v, which will produce a difference in the rate of heating of the two wires proportional to v. Now there is also a current flowing through the instrument proportional

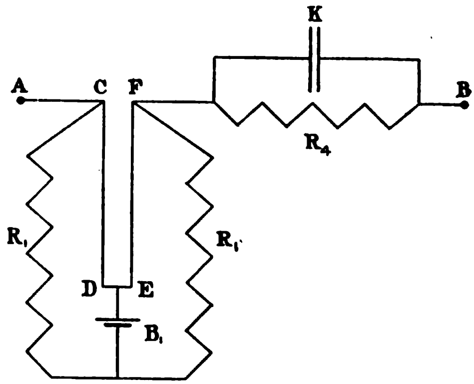

FIG. 10.

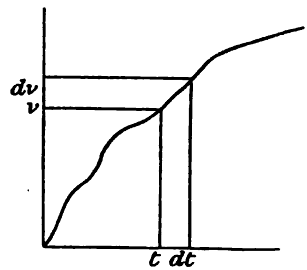

FIG. 11.

to the rate of change of P.D., that is, the current is proportional to $\frac{dv}{dt}$. Consider first the current flowing into the condenser, namely, $n\frac{dv}{dt}$, where n is a constant. This current multiplied by the time dt gives the increase in the quantity of electricity in the condenser in the time dt. Now the difference in the rate of heating of the two wires due to this current is proportional to $n\frac{dv}{dt}$, and if there was no difference in the rates of radiation from the wires, the increase in the difference in temperature in time dt would be proportional to $n\frac{dv}{dt}.dt$, that is, to the increase in the quantity. Therefore, the difference in the temperature of the wires would be proportional to the voltage and to the quantity of electricity that has passed through the wires. But so long as there is a difference in the temperature of the two wires one will radiate heat at a greater rate than the other depending on this difference. To make the difference of temperature at every instant proportional to the quantity stored in the condenser (that is,

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proportional to the voltage), the condenser is shunted with a resistance R_4, and the current through R_4 is proportional to the voltage (that is, a current $m v$ flowing through the strips in series can be arranged to produce a difference in heating effect equal to the radiation losses which are proportional to v). In fact, one may regard the strips as thermal condensers, which are very *leaky*, and to compensate for this leakage one makes the electric condenser equally leaky by shunting it with a resistance.

When these conditions are fulfilled the difference in temperature between the two sets of wires will at every instant be proportional to the voltage across the two points A B, that is, assuming the drop across the instrument itself is small compared with the voltage across R_4. Whether the deflection at every instant will be proportional to the

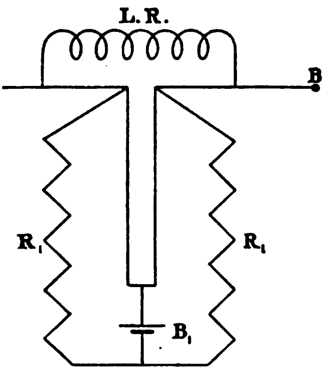

FIG. 12.

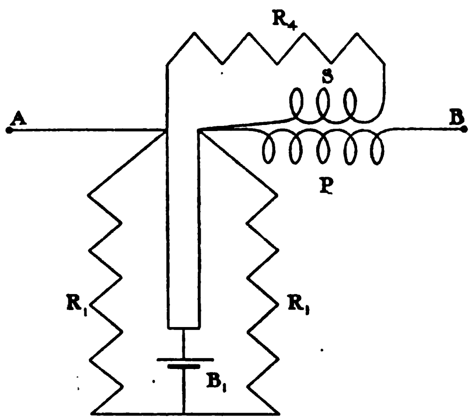

FIG. 13.

voltage across the points A B depends upon the forces acting on the moving parts, on the inertia, and on the damping. This will be considered further on.

To use the instrument for indicating the instantaneous value of the current flowing in a circuit the arrangement shown in Fig. 12 is used where the current is comparatively large compared with that taken by the strips.

A coil with self induction L and resistance R is placed in the main circuit A B. The P.D. across the two strips and the current that flows through them in series is proportional to $c\,R + L\frac{d\,c}{d\,t}$, and if R and L are chosen so that $\frac{R}{L}$ = the ratio of the difference in the rates of dissipating heat to the difference in the quantity of heat stored for a given difference in temperature, then the difference in temperature will be proportional to the instantaneous current in A B.

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To prove this, consider a steady current c flowing through the inductive resistance L R, and that after a time it changes suddenly to another value, $c + \Delta c$. At first there is a voltage drop across L R equal to c R, and this sends a current proportional to c R through the strips.

Then $k\,c\,R =$ the difference in the rates at which heat is being given to the wires,

and $p\,k\,c\,R =$ the steady difference in temperature corresponding to the steady current $c = T$.

Then $$p = \frac{T}{k\,c\,R}.$$

If the current c now change rapidly to $c + \Delta c$ a quantity of electricity will pass through the strips. This will produce a difference in the quantities of heat given to the strips equal to $k\,L\,\Delta c$.

This difference in the quantities of heat given to the two wires will produce an increased difference in their temperature $= \frac{k\,L\,\Delta c}{m\,s}$, where m is the mass of one wire and s its specific heat, and so that this temperature difference may remain constant as long as the current is constant at $c + \Delta c$, the increase in the difference in the temperatures of the wires $\frac{k\,L\,\Delta c}{m\,s}$ must be equal to the increased difference in temperature necessary to enable the wires to exactly radiate the heat due to the increased current Δc.

When this is true—

$$\frac{k\,L\,\Delta c}{m\,s} = p\,k\,R\,(c - \Delta c) - p\,k\,R\,c;$$
$$= p\,k\,R\,\Delta c.$$
$$\therefore \quad \frac{L}{R} = m\,s\,p;$$
$$\text{but} \quad p = \frac{T}{k\,c\,R}.$$
$$\therefore \quad \frac{L}{R} = \frac{m\,s\,T}{k\,c\,R}.$$

That is, the ratio $\frac{L}{R}$ must be equal to the difference in the quantities of heat stored in the two wires to the difference in the rates of radiation of heat from the wires due to the same temperature difference.

If the current flowing in A B is very small then the arrangement shown in Fig. 13 is more suitable, where practically all the current flows through the two strips in series and through the primary of a transformer, the flux in which is practically proportional to the current. The secondary of the transformer is of few turns, and the ampere turns on the secondary are small compared with the ampere turns on the primary. When this is so the current flowing in the secondary is proportional at any instant to the rate of change of the primary current. The current through the strips in series is proportional to—

$$c + k\frac{dc}{dt}.$$

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Where the frequency is high or the rate of cooling slow it is possible to have simply a current through the strips proportional to the rate of change of the voltage as shown in Fig. 14, or of current as shown in Figs. 14 and 15, since the heat gained or lost during a period is practically that due to the current through the strips, proportional to the rate of change of P.D. or current. This is particularly useful when measuring very high differences of potential, as it is possible as shown in Fig. 14 to indicate the instantaneous P.D. on E.H.T. systems without the use of high, carefully insulated and therefore expensive resistances, especially as the curve can be corrected, if the rate of cooling be known.

As the rate of change of the potential difference across the condenser is large, a small condenser of, say, one-hundreth to a thousandth of a microfarad capacity would be sufficient, or an idle

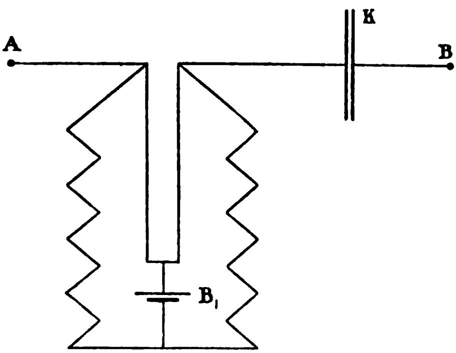

FIG. 14.

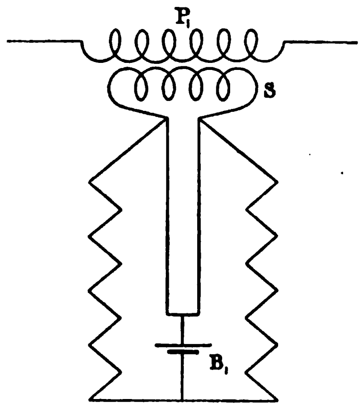

FIG. 15.

feeder could be used as a condenser, the instrument being suitably shunted by a non-inductive resistance to prevent too large a current flowing through it.

This correction would be applied as follows :—

If the curve shown in Fig. 10 had been obtained by a hot-wire oscillograph, and if there had been no compensation for the difference in the rates at which heat was being radiated from the wires, the curve would have to be corrected to show the true value of the voltage at every instant. When there is a deflection δ (say) there must be a difference in the temperature of the two wires and a difference in the rates of losing heat proportional to δ.

The heat lost in any time dt is $p_1 \delta\, dt$, where p_1 is a constant, and therefore the heat lost up to the time t is $\int_0^t p_1 \delta\, dt$. If T is the difference in temperature corresponding to a deflection δ, then the deflection instead of being δ at time t should have been

$$\delta\left(\frac{T+\dfrac{\int^{t} p_1 \delta\, d\, t}{m\, s}}{T}\right)=\delta+\frac{\delta}{T}\,\frac{\int_{o} p_1 \delta\, d\, t}{m\, s}$$

where m is the mass of one wire and s its specific heat.

That is, there has to be a second curve drawn, which represents at any point the integral up to that point of $n\,\delta\, d\, t$ (where n is a factor which is constant for an instrument working under fixed conditions of cooling), and this curve has to be added to the original curve to give the true curve.

There is also another method of using a hot-wire instrument, by which one could obtain a true voltage curve, viz., by allowing only a current proportional to the voltage to flow through the strips. In this case, if there was very little difference in the rates of cooling of the strips, the deflection at any time t would be proportional to $\int_o^t v\, d\, t$.

If the difference in the rates of cooling was appreciable the curve could be corrected as shown above, so as to be exactly proportional to $\int_o^t v\, d\, t$. To get the voltage wave the curve $\int_o^t v\, d\, t$ would have to be differentiated throughout.

The current curve could be obtained in a similar way from the curve $\int_o^t c\, d\, t$.

The current taken by the condenser necessary to work the instrument in all but very small machines will be too small to alter the wave shape of E.M.F. Resonance will be prevented by the resistance of the instrument itself in low voltage systems, and on high voltage systems the instrument can be short-circuited to start with to see if there is any tendency to resonance, and if there is, a resistance can be placed in series with the instruments. The arrangement shown in Fig. 15 is suitable for measuring very small high frequency currents, say telephone currents.

To enable the instrument to indicate the instantaneous power given to a circuit, from the preceding consideration of the current and voltage arrangements it is seen that the difference in the rate of heating of the two strips should be equal to—

$$v\, c + k_2 \frac{d\,(v\, c)}{d\, t},$$

which is equal to—

$$v\, c + k_2\, v \frac{d\, c}{d\, t} + k_2\, c\, \frac{d\, v}{d\, t}.$$

But before considering how to get a deflection proportional to the instantaneous watts given to a circuit, it is advisable to consider how the instrument could be used for indicating the mean power given to a circuit.

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Mr. M. B. Field has shown (Patent 15168^{97}), that if a is the instantaneous value of the current flowing in a circuit, and b is the instantaneous value of the voltage, the instantaneous power given to the circuit is $a\,b$ watts, also as $(a+b)^2-(a-b)^2=4\,a\,b$, that is, the power given to a circuit is proportional to the difference between the sum of the current and voltage squared and the difference of the current and voltage squared.

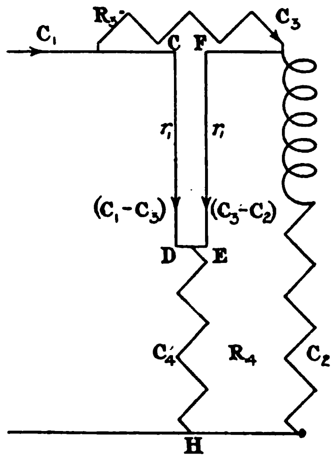

FIG. 16.

Of course a and b may be only proportional to the main current and main voltage respectively. Suppose a circuit arranged as shown in Fig. 16, where R_3 is a resistance in the main circuit, and R_4 is a resistance in series with the strips $r_1\,r_1$ in parallel placed across the main circuit. Let C_1 be the instantaneous value of the current taken from the mains, C_2 that flowing in the circuit in which it is required to measure the power, C_4 that flowing through the resistance R_4, and C_3 the current through the resistance R_3.

Then—

$$C_1-C_3=\text{current through one strip,}$$

and—

$$C_3-C_2=\text{current through other strip.}$$

The difference in the heating of the two strips is equal to—

$$(C_1-C_3)^2r_1-(C_3-C_2)^2r_1,$$

but—

$$C_3R_3+(C_3-C_2)\,r_1=r_1(C_4-C_3+C_2),$$
$$2\,C_2r_1=C_3R_3+2\,C_3r_1-C_4r_1,$$
$$C_2=\frac{C_3R_3+2\,C_3r_1-C_4r_1}{2\,r_1},$$

$\therefore$ Difference in the rate of heating—

$$=r_1\left\{C_4-C_3+C_2\right\}^2-r_1\left\{C_3-C_2\right\}^2,$$
$$=r_1C_4\left\{\frac{C_4r_1-2\,C_3r_1+C_3R_3+2\,C_3r_1}{r_1}-C_4r_1\right\},$$
$$=C_4C_3R_3,$$

which is a very simple expression for the reading of the instrument.

The current $C_4=\frac{v}{R_4}$—when v is the P. D. between H and D E.

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If V is the voltage across the load, then—

$$V = C_4R_4 + (C_3 - C_2)r_1,$$
$$C_4 = \frac{1}{R_4}[V - r_1(C_3 - C_2)].$$

The difference in the rate of heating—

$$= \frac{1}{R_4}[V - (C_3 - C_2)r_1]C_3R_3.$$

When $(C_3 - C_2)\,r_1$ is very small compared with V, and when C_3 is very nearly equal to C_2, the difference in heating is proportional to the product of C_2V, that is, to the watts spent in the circuit.

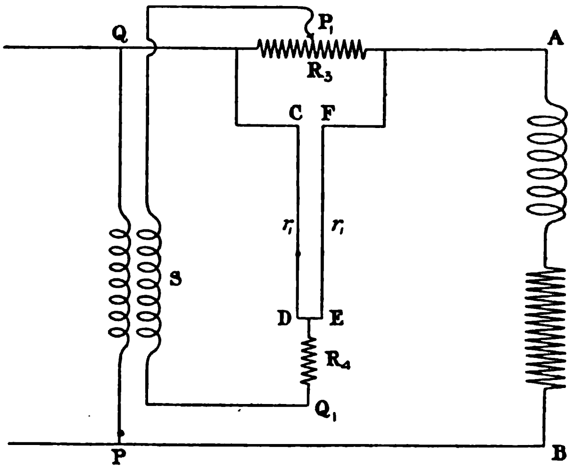

FIG. 17.

It is therefore essential that the actual power spent in the strips themselves shall be very small compared with the power to be measured, if the instrument is to read nearly correctly on low-power factors. In order that the difference of heating shall be as high as possible compared with the total heating of the two strips, it should be arranged that the current shunted through the strips when the pressure current C_4 is taken off, should be nearly equal to the pressure current flowing in the strips when the main current C_2 is reduced to zero, then at full load and unity power factor there will be no current in the right-hand strip.

One of the many ways of using a hot-wire wattmeter in conjunction with a transformer is shown in Fig. 17, where P Q is the primary winding of a transformer and S the secondary. The P.D. across the points P_1 and Q_1 is at every instant equal to Kx potential across

P and $Q = k_3 V$, say, and the current which flows through the strips C D E F in series is equal to $k_3 C$, and is in phase with C since the resistances R_3 and r_1 are non-inductive. The difference in heating in the two strips C D and E F is equal to $4\ k_3 k_4 V\,C$, and therefore the mean difference of heating is equal to $4 k_3 k_4 W$. The difference of heating is proportional to the power spent in the portion of the circuit A B plus the C^2R losses in the resistance R_3 and $r_1 r_1$ due to the main current C.

Errors are introduced by this method due to the transformer winding P having resistance, and to the winding P and S having magnetic leakage; but as a closed iron transformer can be used, the errors due to these causes can be made negligible at all but very low-power factors, say of the order of 0·01, and in this connection the author

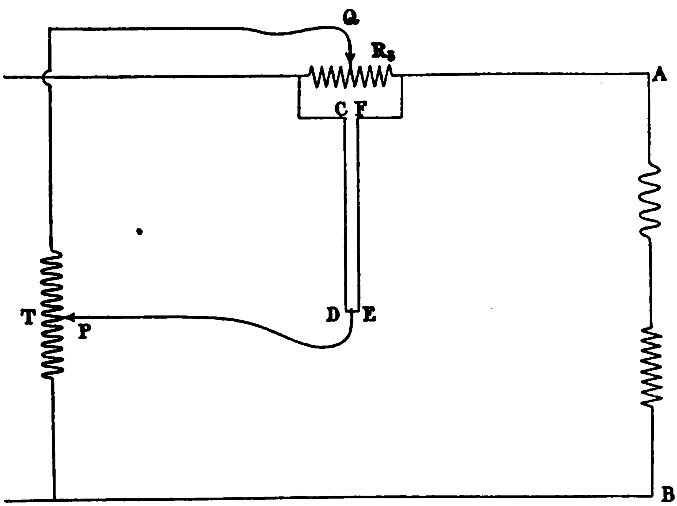

FIG. 18

cannot do better than refer to Dr. Sumpner's original and valuable communication.* The arrangement shown in Fig. 18, where an auto-transformer is used, has some advantages over that shown in Fig. 17, especially where the voltage is small across the load, and where the main current is large. In the first place the C R drop in the auto-transformer does not introduce such a large error, as part of it is now useful in giving a current through the strips, and the leakage coefficient between the whole winding T and the portion P Q, across which the strips are connected in parallel, is reduced.

It is evident, however, that the magnetising current of the auto-transformer must be very small compared with the main current flowing in the circuit A B. When this is the case, the deflection of the instrument will be proportional to the power spent in the circuit Q A B,

* *Journal of the Institution of Electrical Engineers*, vol. 36, p. 144.

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and, since the point Q is the middle point of the resistance R_3, the power spent in the circuit $AB = K$ deflection $-\frac{C^2R_3}{2}$ where C is the R.M.S. value of the current in the circuit.

It is known that a hot-wire instrument arranged to measure watts can be used as an ammeter or voltmeter. Thus suppose in the arrangement shown in Fig. 16 the strip E F is not connected at F to the resistance R_3, then there will be a current through C D proportional to the main voltage across the load V, and therefore the deflection is equal to k_5V^2. If, instead of this arrangement, the point D is connected to R_3 so that the strip C D shunts the resistance R_3, and if the circuit D H is broken, then there will be a current in C D proportional to the main current C_2, and therefore deflection $= k_6C^2$. By the use of suitable constants it is therefore possible to use the same instrument and the same scale for current, pressure, and power.

To enable the instrument to indicate instantaneous watts it is necessary, as was seen above, to have the rate of heating at every instant equal to $VC + k_7V\dot{C} + k_7C\dot{V}$. A method of arriving at this is shown diagrammatically in Fig. 19, where L R is an inductive resistance and R_3 a non-inductive resistance placed in series with the load A B. The two strips C D and E F are placed in series across L R. The resistance R_4 connects the points D and E to the opposite main. The strips G H and I J are connected in series across the resistance R_3, and the points H and I joined to one terminal of the condenser K, the other terminal being connected to the opposite main. In the strip C D there will be a current practically proportional to $V + k_8C + k_9\dot{C}$. In the strip E F there will be a current proportional to $V - k_8C - k_9C$. The difference in the rate of heating of the strips will be proportional to—

$$
\begin{aligned}
&(V + k_9\dot{C} + k_8C)^2 - (V - k_9C - k_8C)^2 \\
&= 2V(2k_9\dot{C} + 2k_8C) \\
&= 4k_8VC + 4k_9V\dot{C}.
\end{aligned}
$$

In the strip G H there will be a current proportional to $C + k_3\dot{V}$, and in I J a current proportional to $k_3\dot{V} - C$. The difference in the rate of heating of these two strips will be proportional to—

$$
\begin{aligned}
&(C + k_3\dot{V})^2 - (k_3\dot{V} - C) \\
&= 4k_3C\dot{V}.
\end{aligned}
$$

It is easy to arrange, as shown in Fig. 20, that the instrument itself shall have a deflection depending on the sum of the lengths of the strips C D and G H minus the sum of the lengths E F and I J, that is, the strips C D and G H really form one strip, and the strips F E and I J another strip. In Fig. 20 the pulleys are replaced by a block which is pulled back in the same manner as the pulleys by a spring. The four

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connections D H I E, instead of being connected D to H and I to E as in the case of the ammeter and voltmeter, are now connected diagonally D to E and I to H, and the wires are still tied together diagonally at the middle point. The letters used in Figs. 19 and 20 refer to similar parts. Now the difference in the heating of these two strips is proportional to—

$$4 k_8 V C + 4 k_9 V \dot{C} + 4 k_3 C \dot{V},$$

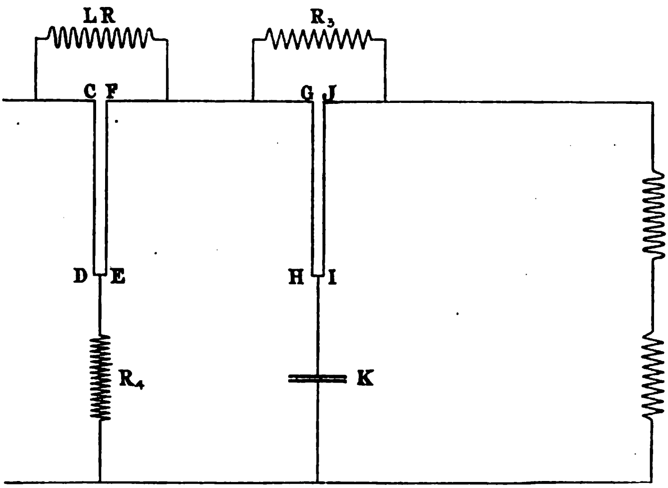

FIG. 19.

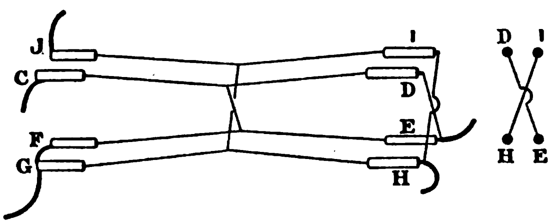

FIG. 20.

and if the values of k_8, k_9, and k_3 are properly chosen, the instantaneous difference in the temperature of the two strips will be proportional to the instantaneous power. If the instrument has a high enough natural period and is properly damped, the deflection will be at every instant proportional to the power.

The author generally mounts three instruments together to show at the same time three waves—say, current, P.D., and power. Three P.D. waves can be shown at once say, the P.D. difference across a resistance and inductance in series, and the P.D. across the resistance, and the P.D. across the inductance separately. As the instruments can

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quite easily have independent exciting circuits, say a small 4-volt battery for each, and as the wires of each instrument can be easily insulated from the others and from the case, it is possible to have a potential of 200 volts or more between the various instruments, as long as care is taken in making the connections.

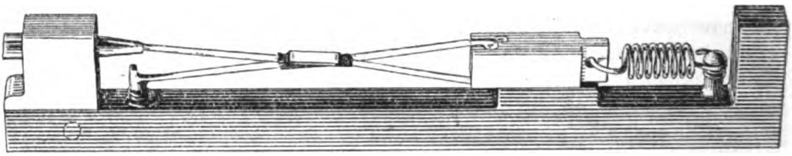

FIG. 20A.

The instrument is made with three elements and is very compact, weighing complete with its levelling screws only $1\frac{3}{4}$ lbs. The mirrors are fairly large, being 4 by 1·5 mm. for projection purposes; the natural period is about $\frac{1}{4000}$th of a second, but it can be made much less by using a smaller mirror and tying back the wires more at the centre; in fact, if necessary, any natural frequency up to 20,000 per second is quite possible.

Fig. 20A shows one element of an oscillograph in which the construction is different from that shown in the preceding figures. The pulleys are removed and replaced by a small block held in tension. The wires are looped over each other, and insulated at the point of crossing. As they are looped over those immediately opposite, the wires themselves must cross diagonally at the tension block. Fig. 20B shows two instruments of this type mounted so as to be able to rotate in two planes about the mirrors. The oscillograph with the smaller mirror (1·5 × 3 mm.) has a natural frequency of 6,000 per second.

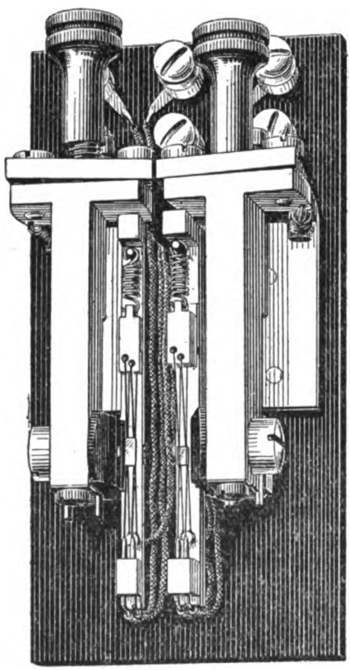

FIG. 20B.

Altering the tension with which the wires are stretched does not alter the natural period very much, the amount the wires are tied back having a greater influence than the tension. In a particular case, altering the tension on one instrument from 10 ozs. to 6·6 ozs. only increased the natural period from $\frac{1}{3200}$th of a second to $\frac{1}{2900}$th of a second.

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It is, of course, true of this instrument, as of all other instruments which are damped in oil or any liquid, that the damped period is longer than the undamped, owing to the oil put in motion by the vibration of the mirror and wires. An oscillograph with a natural frequency of 3,200 in air had a frequency of 2,360 in paraffin oil. This oil was not quite sufficient to damp out the vibrations caused by sending a square wave through the strips, and so the natural period under these conditions could be observed by means of a falling sensitised plate. The ratio of the period in oil to that in air depends on the specific gravity of the oil, on the mass of oil that has to be moved when the strip vibrates, and to a certain extent of the viscosity on the oil.

The sensibility of a hot-wire polarised instrument can only be given for a steady current through it and for a given exciting current. Thus the instrument of the size shown in Fig. 20, when the strips are immersed in castor oil and are excited with 0·5 of an ampere in each, will give a scale deflection of about 30 mm. at a metre scale distance when another current of 0·10 of an ampere is sent through the two strips in series. The deflection it will give when an alternating current of constant R.M.S. value and wave-form is passed through depends on the frequency; thus the instrument would give a wave of approximately 100 mm. amplitude at a metre scale distance, when excited with 0·5 of an ampere and a simple sine wave of alternating current of 40 $\sim$ and a R.M.S. value of 0·35 of an ampere is sent through it, but at double the frequency for the same deflection the current would have to be doubled, except for the smaller radiation of heat that takes place from the wires in the shorter time of a complete period. The fusing current is 4 amperes in this oil. As shown, however, earlier in the paper, the deflection can be made proportional at every instant to the instantaneous voltage across two points, or to the instantaneous current flowing in a circuit independent of the frequency, and this although the instantaneous deflection is not proportional by any means to the current flowing through the instrument itself. Since the difference in rate of heating of the wires is equal to $4\,a\,b\,r$ where b and r are constant, the difference in the rate of heating of the two wires is proportional to a and the temperature difference to $a\,t$ or quantity of electricity that has passed through them. Then, if there is comparatively little difference in the rate of radiation compared with the difference in the amount of heat stored in the strips in a given cycle, or if the difference in the heat radiated can be compensated for, the deflection of the instrument will be proportional to the quantity of electricity that has passed through it, and can be used to indicate the instantaneous flux linking with a circuit. This is very useful for drawing hysteresis loops for iron or showing the instantaneous value of the quantity of electricity stored in a condenser.

Experimental Results.

Voltage Curves.—One of the first machines for which the voltage curve was obtained was the Pyke and Harris inductor alternator at

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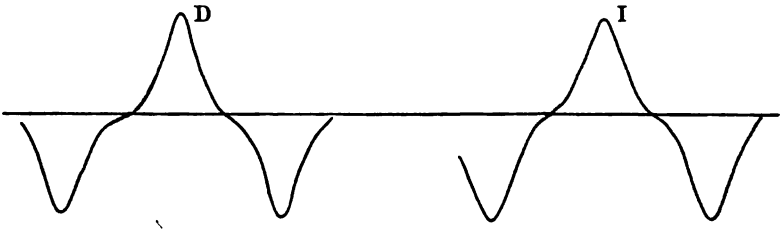
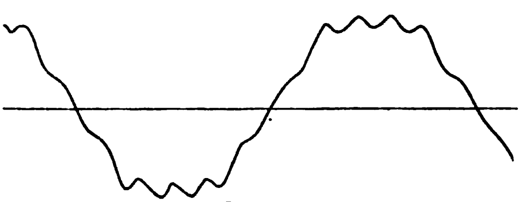
the Central Technical College. This machine was the one from which Mr. Duddell obtained a curve by his oscillograph in its early stages and compared it with that obtained by the point-by-point method. He showed that the two curves were practically identical, so that the author had only to compare a curve obtained by his oscillograph with one obtained by a Duddell instrument. This is shown in Fig. 21, D being the curve obtained on a Duddell projection oscillograph and I the curve obtained on the author's instrument.



Duddell. Irwin.

FIG. 21.

The two curves are so nearly alike that it is almost impossible to detect any difference even when two tracings of the curves are superimposed. In this case the author's instrument was damped in paraffin oil, which was found afterwards not to give quite enough damping. This want of damping is shown more clearly in Fig. 23, which represents a wave having ripples of a much higher frequency taken on a falling sensitised plate. Fig. 22 shows the same wave as recorded by a Duddell oscillograph having a natural frequency of 10,000 per second.



Duddell

FIG. 22.

It was found by sending a square wave of current through it that the Duddell was slightly over-damped.

Fig. 24 shows two curves for current and P.D. on a non-inductive load, and it will be seen that they are practically in phase with each other and of the same wave form. In this case the wires were properly damped in castor oil. The drop of potential across the inductive resistance L R was only about 1·5 volts, and therefore did not alter the current or the angle of lag much, as the voltage across the

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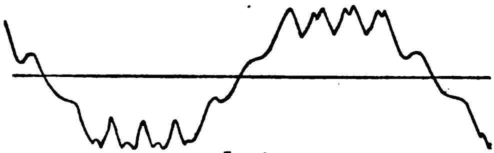
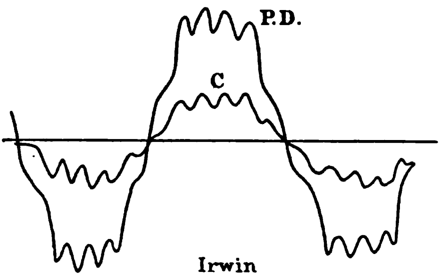
non-inductive resistance R was about 150. Fig. 25 shows the current and P.D. curves on a partially inductive load. Fig. 26 the current, P.D., and power curves on a non-inductive load, and Fig. 27 the current P.D. and power curves on an inductive load. It is evident



Irwin
FIG. 23.



Irwin
FIG. 24.

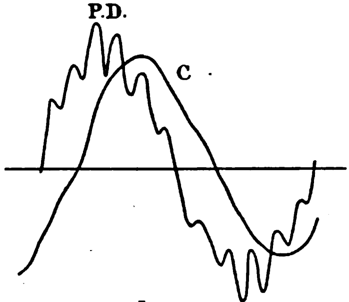


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FIG. 25.

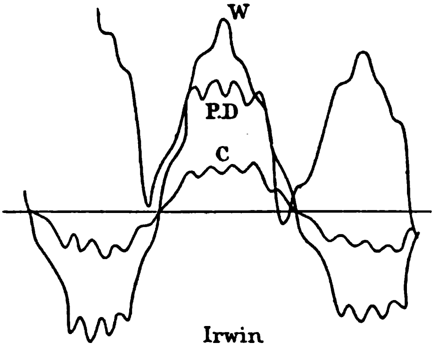

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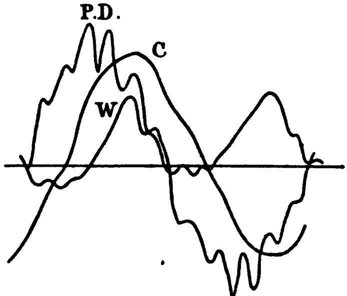
FIG. 26.



Irwin
FIG. 27.

that the power curves are incorrect, but it is not easy to adjust the currents in the wattmeter wires to the theoretical values they ought to have.

The author has developed a new method of damping by which it is possible to dispense with the damping oil altogether, or else to have a

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damping liquid much less viscous than castor oil and not affected by variation in temperature.

The method consists in so damping the electric current through the instrument that the deflection is proportional to the quantity it is desired to record. Suppose in Fig. 10 a resistance R_6 is inserted in series with the condenser K, and the resistance R_4 is now placed across both the condenser and R_6. Then when a nearly square wave of P.D. is applied across the points A B the current flowing into the condenser when the P.D changes suddenly by an amount ΔV is proportional to $\frac{\Delta V}{R}$. The quantity of electricity that flows into the condenser in a very small time dt is proportional to $\frac{\Delta V}{R_6} dt$. This quantity flowing through the strips will produce a difference in their temperature proportional to $\frac{\Delta V}{R_6} dt$, and therefore the initial force acting on the moving parts is reduced as the resistance is increased. This initial diminution of the force acting on the moving parts is to be depreciated in as much as it reduces the steepness of the curve of P.D. If the resistance R_6 was very large, the quantity of electricity in the condenser would increase comparatively slowly and the oscillograph would indicate this accurately, and would therefore show the P.D. curve rounded off; just as with ordinary oil damping the steepness of the curve is reduced and the curve rounded off as the viscosity of the oil is increased.

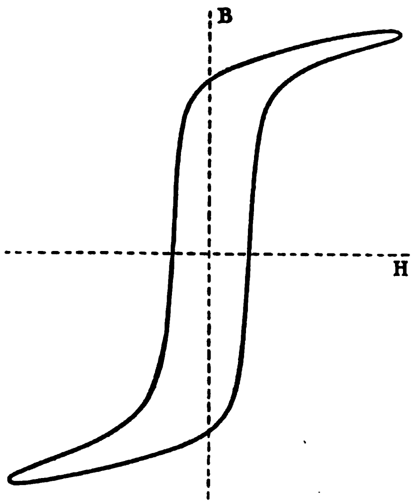

FIG. 28.

As the resistance R_6 is decreased the rounding off of the curve diminishes, and the mirror would eventually have a throw greater than that corresponding to the impressed voltage across A B. The critical resistance is that which limits the deflection of the instrument when a sudden P.D. is applied to what it would have if a steady P.D. of the same value were applied across A B. It is possible to damp the current wave by putting a resistance in parallel with the self-induction across which the strips are placed. This is necessary when the damping due to the strips themselves is not sufficient. When a transformer is used, it is only necessary to increase the secondary ampere-turns compared with the primary ampere-turns to secure increased damping.

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The hysteresis curve shown in Fig. 28 is from the iron in a transformer. At this point it would be well to describe the arrangement of drawing rectilinear curves adopted by the author. There have been rectilinear curves drawn by a moving spot of light for hysteresis and other curves, by having, say, two oscillographs, one indicating flux, and the other P.D. with the plane of the mirrors normally parallel and their axis of rotation at right angles, or the equivalent of this obtained by rotating the plane in which a beam of

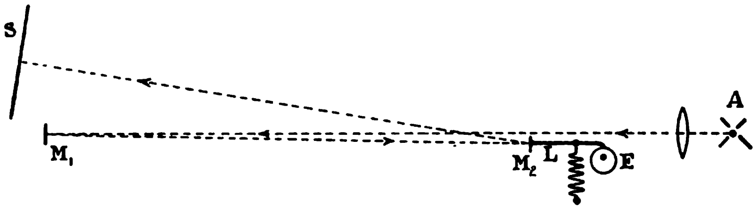

FIG. 29.

light reflected from the mirrors would vibrate by a reflecting prism as shown by Morris and Catterson-Smith* and by Witteman.†

There is, however, no necessity to go to the trouble of fitting up this special arrangement, as by the simple arrangement shown in Fig. 29 the curve can be drawn. A is a source which gives a beam of light on M_1, the mirror on the oscillograph. This mirror, which has a deflection proportional, say, to the magnetising current of a transformer, reflects the beam on to the mirror M_2, which has its axis of rotation at right angles to M_1. If the mirror M_2 is oscillated by a synchronous motor, and if the phase of the displacement is exactly in phase with the flux in the transformer, then the beam of light will draw out a hysteresis curve on the screen S. To effect this an eccentric E is placed on the shaft of a two-pole synchronous motor of the type shown diagrammatically in Fig. 30, and a lever L (which oscillates the mirror M_2 about its centre) is kept pressed against it. The lever is fairly long in comparison with the throw of the eccentric, so the motion of the mirror is nearly simple harmonic. A sine wave P.D. is impressed on the transformer, then the back E.M.F. must be also a sine wave and the flux a sine wave; therefore if one can vary the position of the eccentric on the shaft until its maximum throw corresponds with the maximum flux in the transformer, and if the mirror M_1 has a deflection proportional to the magnetising current, then the beam of light will draw out the hysteresis curve.

There is another method of drawing hysteresis loops where the E.M.F wave is not nearly a sine wave, namely, to compel the magnetising current to be a sine wave by putting a large self-induction

* *Journal of Institution of Electrical Engineers*, vol. 33, p. 1019, 1904.
† *Elektrotechnische Zeitschrift*, vol. 25, p. 885.

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without iron in the core in series with a small magnetising coil wound on the test piece of iron. A hot-wire oscillograph is connected across this magnetising coil or across a secondary. Since the deflection of the oscillograph is proportional, if the frequency is high, to the quantity, it will be proportional to the flux, therefore one has only to make the deflection of mirror M_2 proportional to the magnetising current and the hysteresis loop will be drawn out. The objection to this method is that there is no exact method of compensating the strips for their difference in rate of losing heat, since to secure compensation would require a current proportional to the flux as well as to the rate of change of flux to be flowing through the instrument at every instant.

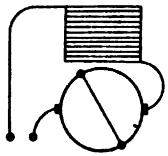

FIG. 30.

HOT-WIRE WATTMETER TESTS.

The instrument on which these experiments were carried out was arranged in tubular form (Fig. 30A), so as to be able to go inside the tubular air-tight casing, and was constructed on the same principle as the hot-wire oscillograph, except that the small plane mirror is replaced by a concave mirror $\frac{3}{8}$ in. in diameter. An ideal hot-wire wattmeter should have the following properties :—

1. High sensibility.*
2. Deflection proportional to the difference in the rate of heating of the two strips and independent of the actual heating of the strips.

If condition 2 is fulfilled then it should be possible :—

(*a*) To pass a current of any value that would not damage the instrument through the two wires in series without producing any deflection.

(*b*) To apply any voltage within limits across the two strips in parallel without producing any deflection.

(*c*) To have a deflection proportional to the square of the current through one strip only.

The following particulars of the instrument may be of interest :—

Total effective length of wire for each strip ...	10 cms.
Diameter of wires...	0·005 of a cm.
Distance apart	0·15 of a cm.
Material platinum, silver...	
Resistance of strips	{ 10·39 ohms. 10·30 ohms.

The natural period of the instrument was $\frac{1}{50}$th of a second at first, and on account of it being so high it was liable to get in phase with the variation of heating in the instrument on alternating current. The mirror was weighted with lead to stop this movement.

Sensibility, 290-mm. deflection at a scale distance of 1 metre for a current of 0·2 of an ampere through one strip; that is an expenditure of

* Not so desirable if a pressure transformer is used.

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power of 0·4 of a watt. The author would suggest as a sensibility factor for hot-wire wattmeters the term—

$$\frac{\text{deflection}}{\text{scale distance} \times \text{difference in watts dissipated.}}$$

The factor in the present case comes to 0·72, but could easily be increased to a higher value by employing finer wires in the instrument, by using longer wires not tied back so far, or by putting the wires nearer together. Table I. shows the approximation to which condition 2 (*a*) and (*b*) mentioned above is satisfied, namely, the result of passing the same current through the strips in series, and of putting the strips in parallel and passing a current through them. There would have been no deflection if the instrument had been perfect.

It is seen from Table I. that to improve the readings one of the strips would have to be shunted so as to make the mean deflection more nearly zero, as at present the deflection is always in one direction. A small resistance should also be placed in series with the same strip to reduce its mean deflection to nearly zero. The deflection follows no definite law, and is probably due chiefly to convection currents cooling one wire more than the other and perhaps slightly due to a change in the emissivity of the wires at different temperatures. That convection currents are to a certain extent operative can be shown by tilting the instrument into various positions from the vertical, which increases or decreases the deflection in each case. This can easily be overcome by shielding the wires from each other so that the convection current from one wire does not influence the other. By adjusting the strips but without any shielding it was possible to reduce maximum deflection to less than 5 mm. for any safe current. The effect could also be eliminated by taking the mean of the deflection in each direction.

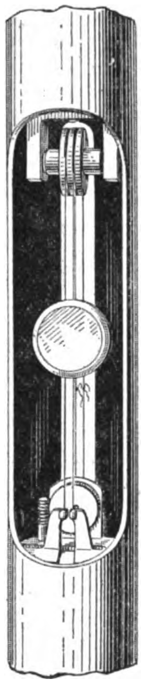

FIG. 30A.

The curve given in Fig. 6 is from this wattmeter, and shows the deflection plotted against the current in centi-amperes sent through the two strips in series, when the current through the strips in parallel is constant at 0·1 of an ampere. It will be seen that the deflection is almost exactly proportional to the series current. This corresponds to the case of a wattmeter on a non-inductive load where the difference in the rate of heating is proportional to the current multiplied by the voltage. A test was undertaken to find out how altering the tension on the strips altered the sensibility. Decreasing the tension on the strips from 8 ozs., the normal tension, to 4 ozs., the sensibility was increased by 15 per cent. It was also found that the deflection when

TABLE I.

Current.	Deflection Strips in Series.		Deflection Strips in Parallel.	
	Ascending.	Descending.	Ascending.	Descending.
	mm.	mm.	mm.	mm.
0	0	0	0	0
0·1	6	10	7	—
0·15	8	5	7	—
0·2	10	3	7	—
0·25	2	2	5	—
0·3	—	—	2	—
0·35	—	—	0	−5
0·4	—	—	−8	−10

a current was sent through one wire only was proportional to (current).[2] This small change of sensibility, due to change of tension, is of considerable importance, since it shows that slight alterations of the spring, which may arise from change of temperature, will only produce a very small effect on the sensibility of the instrument. The tension of 8 oz. was kept on, for although less sensitive the deflection was more constant for a given difference in heating.

With a view to obtaining increased sensibility, the wattmeter was enclosed in its case and the case exhausted. The curve in Fig. 31 shows how the deflection is increased for a constant difference in the watts dissipated in the strips. It will be seen that for a small diminution in the pressure the sensibility is very little increased, but when the pressure falls below 50 mm. of mercury, the increase in sensibility is very rapid. The total increase in sensibility from atmospheric pressure to 12 mm. of mercury is 70 per cent. The shape of this curve is very important as it shows that unless one is able to keep a constant reduced pressure in the instrument the sensibility will vary very much, and this makes this arrangement commercially impracticable. The most important test for a wattmeter is whether inherently it will read correctly the difference in the watts expended in the two wires, independent of the absolute watts expended in each wire. This was partially shown in Table I., where the difference in heating was zero.

Fig. 32 shows a typical curve for this hot-wire instrument on a non-inductive load. The wattmeter readings are plotted against the product of amperes and volts. As a matter of fact it was as much a calibration

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of the *ammeter* as of the wattmeter, as the ammeter used was only a commercial hot-wire one.

Fig. 33 shows a typical curve for the wattmeter on an inductive load of power factor about 0·15. It will be seen that the deflection is practically proportional to the watts + a constant, and any error is likely to be introduced by the transformer, since inherently the wattmeter will be right to 1 part in 80 on a non-inductive load, if the

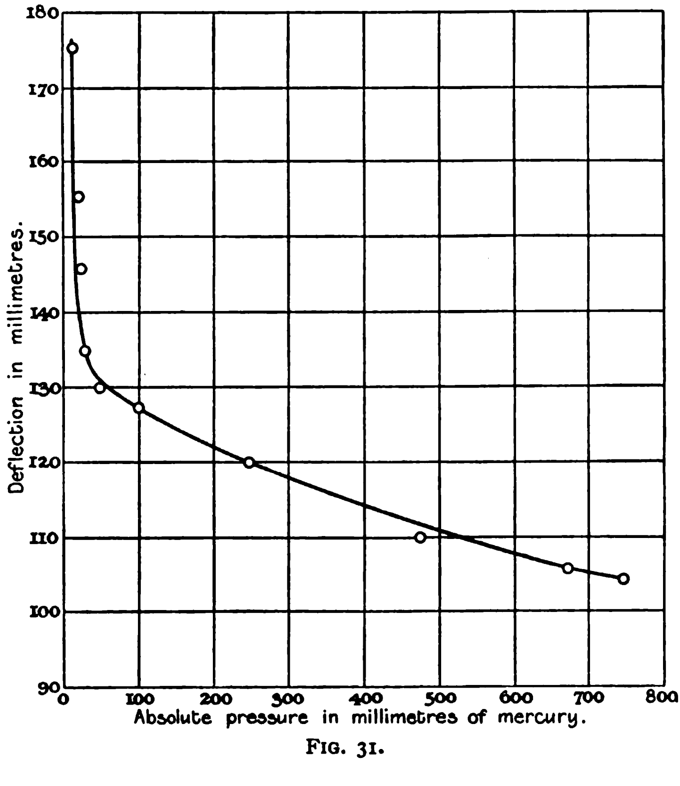

FIG. 31.

deflection is taken in one direction only, and to a much higher degree if the mean of the deflections in both directions is taken. On a power factor of 0·1 the maximum inherent error is about 15 per cent., and the error if the mean deflection is taken is probably about 5 per cent. These are the inherent errors due to the deflection of the instrument not being strictly proportional to the difference in heating, and they can be reduced very largely by better design and more careful shielding of the wires from convection currents of air.

The experimental results given above are only a few of a great many experiments carried out at the Central Technical College, and the author has to thank Professor Ayrton and Mr. Mather for the facilities

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afforded and for help in connection with the research. Messrs. Carr and Tubini carried out the investigation on the hot-wire oscillograph, and Messrs. Kinnes and Parry that on the hot-wire wattmeter. The

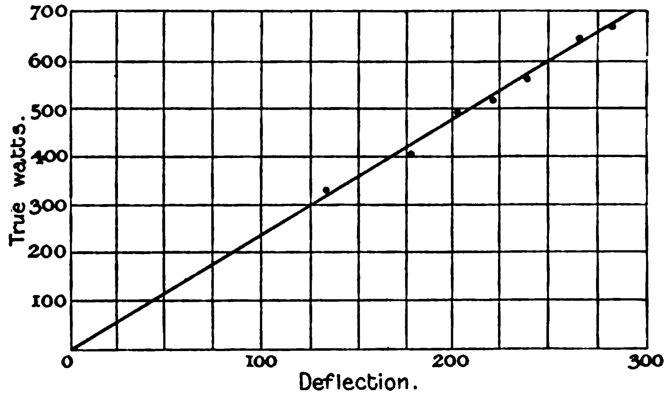

FIG. 32.

success so far attained is due in a large measure to the resource and care displayed by these students in carrying out experiments.

The author is also indebted to Messrs. McEwen, Denton, Robson, Haworth, and Mackinney, his colleagues, for help and advice, to Mr. Alexander Russell for assistance in connection with the calculations on

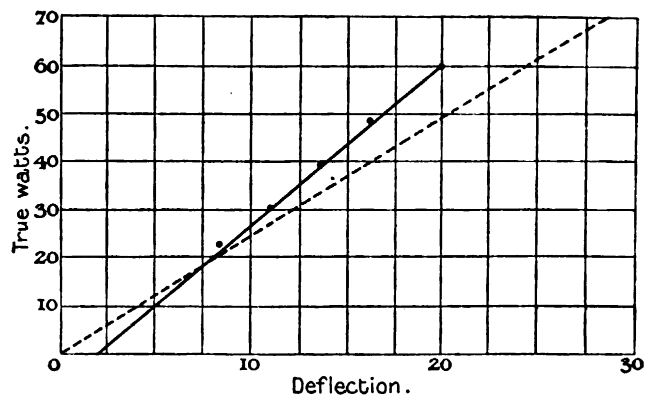

FIG. 33.

the free period of instrument, and to Dr. Watson for advice on the making of small mirrors. The instruments were made by Mr. F. W. Andrews, instrument maker to the college, whose practical skill overcame a number of difficulties met with in the construction. Mr. Howe has kindly revised and corrected the paper.

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DISCUSSION.

Mr. A. CAMPBELL: I should like to congratulate my friend and old pupil, Mr. Irwin, on the number of beautiful apparatus he has put before us. In the design of each of them there are many difficult points which he has overcome by skill and inventiveness, so that from each of the different instruments we can learn a great deal. To begin with, one feels quite astonished that the hot-wire principle has been successfully applied to the construction of an oscillograph, for we all know that one of the main defects of hot-wire instruments is their sluggishness. The way in which the author has got over that difficulty is most ingenious. Perhaps I may add a few words of additional explanation, which will help some of us to see more clearly how the condenser K helps the working of the instrument by compensating for the thermal lag in the heating and cooling of the wires C D and E F. These wires are, to begin with, practically kept at the same temperature above that of the surrounding oils by the steady current in them, and when the alternating current is passed it reduces the current on the one side instantaneously and increases it on the other side, and thus tends to make a difference of temperature between the wires, which reverses sign twice in each period. The reason why a condenser can hurry up the heating of the wires and compensate for the thermal lag is made possible by the fact that the curve which shows the rise of temperature in a wire supplied at a uniform rate with energy is similar to the curve which shows the current going into a condenser through a resistance when a fixed voltage is applied to the terminals of the combination of the resistance in series with the condenser. I may mention a simple experiment that was suggested to me by Mr. Irwin's hot-wire instruments. By fastening a thin wire in tension to the centre of a mica diaphragm I constructed a hot-wire telephone, and this gave a musical sound when an alternating current was passed through the wire. This illustrates the fact that even in air such a wire follows, by its expansion and contraction, the quick periodic rise and fall of an alternating current, the effect being strong enough to set the telephone diaphragm vibrating. Mr. Campbell.

Mr. W. DUDDELL: At this late hour I shall confine my remarks to one or two points. I wish to compliment the author on the very ingenious instrument he has brought before us. At first sight it would not appear that one could use a thermal instrument in any way to make an oscillograph, and I was much surprised when I first saw the title of the paper—"Hot-wire Wattmeters and Oscillographs." I am all the more interested in the most ingenious methods by which he has overcome the thermal lag in the instrument. It reminds me very much of a method that was employed by M. Abraham some years ago to overcome the lag when using an ordinary moving-coil galvanometer as an oscillograph. M. Abraham wanted to use a moving-coil galvanometer as an oscillograph, and he compensated for the errors introduced by the instrument by so distorting the current through the galvanometer, Mr. Duddell.

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Mr. Duddell.

by means of self-induction and mutual induction in the circuit, that the instrument indicated the real wave-form. The author has, by his arrangement of condenser and resistance, actually distorted the current flowing through his oscillograph so that the deflection of the oscillograph really shows the instantaneous voltage applied between A and B. Mr. Campbell, in his remarks with regard to this arrangement, assumed that the voltage between A and B was constant. I do not know what is the value of the capacity of the condenser K; but if the capacity is considerable, then on small machines the effect of the condenser K will be to distort the wave-form of the alternator itself. The E.M.F. wave between A and B cannot be really constant, as it will be distorted by the condenser K. With small machines, or on circuits where the available power is small, the condenser K must be kept small. In big plants, such as in central stations, I do not suppose the value of condenser K will affect the results. Another point to which I should like to draw attention is the watt curve. It is very interesting that the author should have been able to show on the screen for teaching purposes the power flowing in an alternating-current circuit. I had the pleasure of showing for Professor Carus-Wilson at the Royal Institution some years ago some watt curves in which the field magnet of one of my oscillographs was excited by the main current, and the strips had flowing through them a current proportional to the potential difference. By using a low saturation in the iron of the field magnet it was quite possible to show the watt curves. The interesting point with the watt curve is to have a zero line. The apparatus exhibited to-night did not have a zero line fitted up; but I understand, from what Mr. Irwin said, that it will be fitted with a zero line later. When there is a zero line on the watt curve, it will be noticed that the watt curve is on one side of the zero line when there is resistance; but if there is self-induction in the circuit, both positive and negative watts flow into the circuit, which forms an extremely useful example for teaching purposes, demonstrating the fact that a self-induction does not necessarily absorb power, although it tends to stop the current from flowing through it. The difficult experiment by means of which Mr. Irwin attempted to show the hysteresis loop on the screen was extremely interesting. I only wish the loop had stood still a little better during the experiment, so that one might have been able to see its shape. It is of the utmost importance in the design of transformers to know exactly the real shape of the hysteresis loop of the core of a transformer while it is in use. The hysteresis loops which are obtained by the ballistic method or by slow methods do not appear to give the same watt loss in the transformer as the hysteresis when measured by either the wattmeter method or by tests on the complete transformer; and we are very anxious to obtain some easy method of recording these loops. Mr. Irwin refers in the paper to Mr. Morris and Mr. Catterson Smith's paper in which they used oscillographs for obtaining complete hysteresis curves. I had hoped that Mr. Morris or Mr. Smith would have gone on with the matter a little further; but no further results have appeared from their

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work, and I fear they have dropped it. I only hope that Mr. Irwin, in going on with his new form of oscillograph, will enable us to get these loops easily, so that we may be able to know exactly the losses in a transformer under work. Mr. Duddell.

Mr. Campbell referred to a most ingenious idea of a hot-wire telephone, which he sketched on the board. One remark he made rather surprised me. He said that when he sent an alternating current through the wire connected to the diaphragm he heard the note corresponding to the alternating current. I should have expected that Mr. Campbell would have heard the octave above it, because the wire should heat at each half-period of the current, and therefore it should have deflected at twice the frequency of the current. [Mr. CAMPBELL: I have no doubt that was so.] If Mr. Campbell had polarised the wire by the method used by Mr. Irwin to obtain the polarisation, I have no doubt he would have heard the fundamental.

Dr. C. V. DRYSDALE: The principal thing that struck me in explanation of this very interesting instrument was the use of the shunted condenser. It seems to me, on the spur of the moment, that perhaps the best explanation that can be given of it is that in any such arrangement as this, where there is a thermal lag, it may be compared very well with a self-induction. All kinds of lags in instruments or machinery of any kind, whether due to inductance, mechanical inertia, or thermal lag, when dealt with electrically, practically come to the same thing as an inductance of the circuit. It appears to me that the best way of thinking of Mr. Irwin's most ingenious device is that he uses a shunted condenser to wipe out self-induction in the way in which we very commonly do for alternate-current instruments such as wattmeters. Dr. Drysdale.

(*Communicated*): The justification for the analogy in this case is seen clearly by a simple mathematical proof. If H is the quantity of heat produced per second in the strip by the current, this heat is divided into two parts, one of which is dissipated in radiation, conduction, and convection, while the other heats the strip. For a small temperature rise compared with the absolute temperature, the heat dissipated per second is proportional to the rise of temperature t, while that expended in heating the strip is proportional to the rate of change of t. Hence we have $H = a\,t + b\,\dot{t}$.

If t_1 is the rise of temperature in the first strip and t_2 that in the second, we have—

$$a\,t_1 + b\,\dot{t}_1 = H_1 = (C + c)^2 r$$
$$a\,t_2 + b\,\dot{t}_2 = H_2 = (C - c)^2 r,$$

from which $a\,\theta + b\,\dot{\theta} = 4\,c\,r.C$ where $\theta = t_1 - t_2$ the difference of temperature between the strips. (This is exactly analogous to the equation $r C + L \dot{C} = V$ for an inductive circuit.) But if V be the difference of potential at the terminals of the shunted condenser in series with the strips—

$$C = \frac{V}{R} + K\dot{V}.$$

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Dr. Drysdale.

Hence we have—

$$a\theta + b\dot{\theta} = 4Cr\left(\frac{V}{R} + K\dot{V}\right),$$

and if $\frac{b}{a} = KR$, or the thermal time-constant equals that of the condenser, θ will be proportional to V. In other words, the shunted condenser compensates for the thermal lag almost precisely as it does for inductance. The lag due to inertia of the strips is, of course, corrected in the same manner.

These hot-wire devices of Mr. Irwin's are capable of many valuable applications. Some years ago I devised a most simple hot-wire wattmeter for 3-phase circuits on this principle, and I hope Mr. Irwin will apply the skill he has devoted to the oscillographs in the direction of such instruments.

Mr. Irwin.

Mr. J. T. IRWIN (*in reply*): I am very much interested in the experiment Mr. Campbell has described in which he was able to use a hot wire to actuate the diaphragm of a telephone.

I have no doubt but that this could be arranged by using suitable wires polarised by direct current, and compensated for their heat capacity to give a very loud-speaking receiver.

I am the more interested in this because I was shown a very ingenious hot-wire telephone by Mr. Brown, of Finsbury Avenue, which he had made about six years ago, and by which he was able to hear ordinary telephone messages. Unfortunately he did not persist with this instrument, otherwise he might have put it to some useful purpose by now.

Mr. Campbell shows the analogy between the thermal and the electrical condenser, and this is of considerable importance when one wishes to use a polarised hot-wire instrument as a ballistic coulombmeter as referred to on page 620.

If a quantity of electricity is passed quickly through the instrument a difference in temperature between the two wires is immediately established, and at the end of its first throw there is definite proportion of this initial difference in temperature, and the throw can be shown to be proportional to the quantity if the damping is neglected. A coulombmeter on this principle has the advantage of having no magnetic or electrical damping, but it could not be used for measuring very small quantities owing to its low sensibility.

I referred in the paper to the possible distortion of the wave of E.M.F. by the condenser current, and mentioned that in the case of very small machines where a current of 0·1 to 0·5 of an ampere would produce an appreciable reaction voltage or resistance drop, there would be distortion.

It is impossible to get the true E.M.F. of a machine as long as there is any current taken by the measuring instrument, as even the current through a resistance will produce distortion. These effects are, however, very small, and are quite negligible in any practical machine. As a matter of fact, it could be arranged to dispense with the con-

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denser by shunting the strips with an inductive resistance, and putting a large resistance in series with it. In experimental or research work the condenser used would be of the order of a microfarad up to 5 microfarads depending on the voltage and on the amplitude required. Mr. Irwin.

Mr. Duddell's reference to the work done by M. Abraham in adapting a long-period galvanometer as an oscillograph is of much interest, and one can only suppose that the method turned out too complicated for ordinary use. Perhaps M. Abraham started his investigations with a galvanometer that had too long a period, and therefore required too much compensation for the inertia of the moving parts. It is, of course, possible to think of a hot-wire oscillograph as having the current through it distorted so as to enable it to indicate the instantaneous current or potential difference, but I prefer to think of it as a coulombmeter to measure the instantaneous quantity and to think of the resistance in parallel with the condenser as supplying the heat lost by the thermal condenser. It is interesting to know that Mr. Duddell was able to get a curve of instantaneous power by a suitable design of his oscillograph. It would appear that hysteresis and eddy currents would introduce errors, and these errors would make it difficult to get the true wave-form for the higher harmonics. I have been able to get watt curves much nearer the true value than these shown in the paper, but, as I mentioned, it is rather too complicated for general use except it were made up as a standard experiment with the proper resistances, inductances, and capacities.

The method I have shown for drawing hysteresis and other rectangular curves is of very easy application, as one can arrange to use a standard oscillograph outfit, the only alterations necessary being the substitution of a cam to give the oscillating mirror simple harmonic motion instead of uniform angular motion and the running of the synchronous motor at a speed equal to the frequency instead of, as usual, at a speed equal to half the frequency.

I hope to be able to investigate still further, as suggested by Mr. Duddell, the hysteresis loss under working conditions as carried out to some extent by Mr. Morris and Mr. Catterson-Smith.

Dr. Drysdale shows very clearly that the difference in temperature of the wires is proportional to the instantaneous difference in potential across the condenser, and this difference of temperature is independent of the frequency; this means that, provided the natural frequency of vibration of the instrument is high enough, the instrument will indicate accurately, both in magnitude and phase, any wave, however rapid its change. I wish to draw special attention to this point, as it appears to be not generally understood.

The President : I will ask you to accord a hearty vote of thanks to Mr. Irwin for his exceedingly interesting paper. The President.

The resolution was carried by acclamation.

The meeting adjourned at 9.45 p.m.

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MANCHESTER LOCAL SECTION.

A NEW TYPE OF INDUCTION MOTOR.

By Louis J. Hunt, Associate Member.

(*Paper read March* 19, 1907.)

The motor described in this paper possesses all the characteristics of the ordinary type of slip-ring induction motor, but differs from it in the arrangement of the windings. These are arranged to permit of the starting or regulating resistances being connected to the stator windings instead of to slip rings in the ordinary manner. The machine is an improved form of "cascade" motor, having two magnetic field systems super-imposed upon one another in the same core body. The second field has its origin in the rotor, and consequently induces secondary currents in the stator windings.

The "cascade" system is well known, especially in connection with polyphase railway motors. The La Cour motor converter, in which an induction motor and a continuous-current generator are connected in cascade, is another example of its use. The system as applied to two induction motors of ordinary design may be briefly described as follows: The two machines are arranged to work in conjunction, the stator windings of the first being connected directly to the supply mains. The slip rings of this motor are coupled to the stator windings of motor No. 2, the slip rings of which are connected through the starting and regulating resistances. If both machines have the same number of poles, and if the windings are so connected that the magnetic fields rotate in the same direction, the synchronous speed at which the two motors will rotate, when cascade-connected, will be half that at which either would revolve if independently coupled to the line. If, on the other hand, the number of poles be dissimilar and the fields rotate in opposite directions, the speed of the combination will be equivalent to that of a motor having a number of poles equal to the difference between the numbers of poles of the two machines of the two motors. As an example, if one motor have six poles and the other two poles, the cascade speed will be that of a motor having four poles.

Instead of electrically connecting the rotor and stator windings of motors Nos. 1 and 2, the same effect may be obtained by coupling the two rotor windings and connecting the starting or regulating resistances

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to the stator windings of the second motor. Slow-speed motors have been built on these lines, the two stators and rotors being supported by a common housing. The magnetising current of the second motor is supplied from the rotor windings of the first machine. This current has to be balanced by a wattless current supplied by the line, and is additional to the magnetising current required to produce the field of motor No. 1. The total magnetising current drawn from the supply mains is consequently equal to the sum of the currents required by the two machines. The equivalent inductance of the combination is equal to the sum of the inductances of the two machines. If the two motors are wound for the same number of poles, and have the same electrical characteristics, the maximum energy current which they will take from the line, when connected in "cascade," will be somewhat less than half that taken by one motor when working independently. The chief

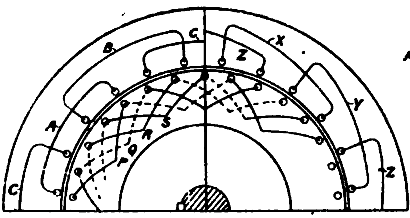

FIG. 1.

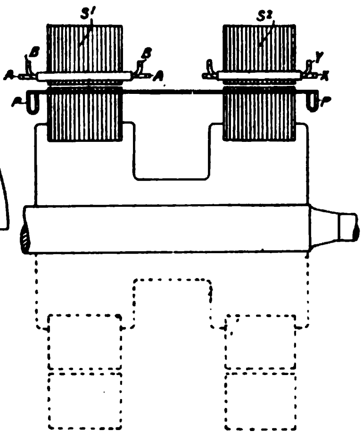

FIG. 2.

objections to a motor consisting of two stators and two rotors or one common rotor are—the high cost, low efficiency, owing to greatly increased copper losses, low power factor, and small overload capacity. Patent office records show that considerable attention has been given to the problem of producing a cascade motor which should be free from the objections enumerated above.

The cascade system of control was devised independently by Steinmetz in the United States and by Görges in Germany, in 1897. In 1901 Professor Silvanus Thompson patented a motor which, although having only one stator and rotor, is equivalent to two cascade-connected motors. In this machine the stator is divided into several segments, alternate segments carrying primary and secondary windings. The primary windings are connected directly to the line and the secondary ones to the starting or regulating resistances. The rotor

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carries a wave winding, which is acted upon by the magnetic field produced by the primary currents, and in its turn reacts upon the secondary windings of the stator. The primary and secondary stator windings are rendered mutually non-inductive by

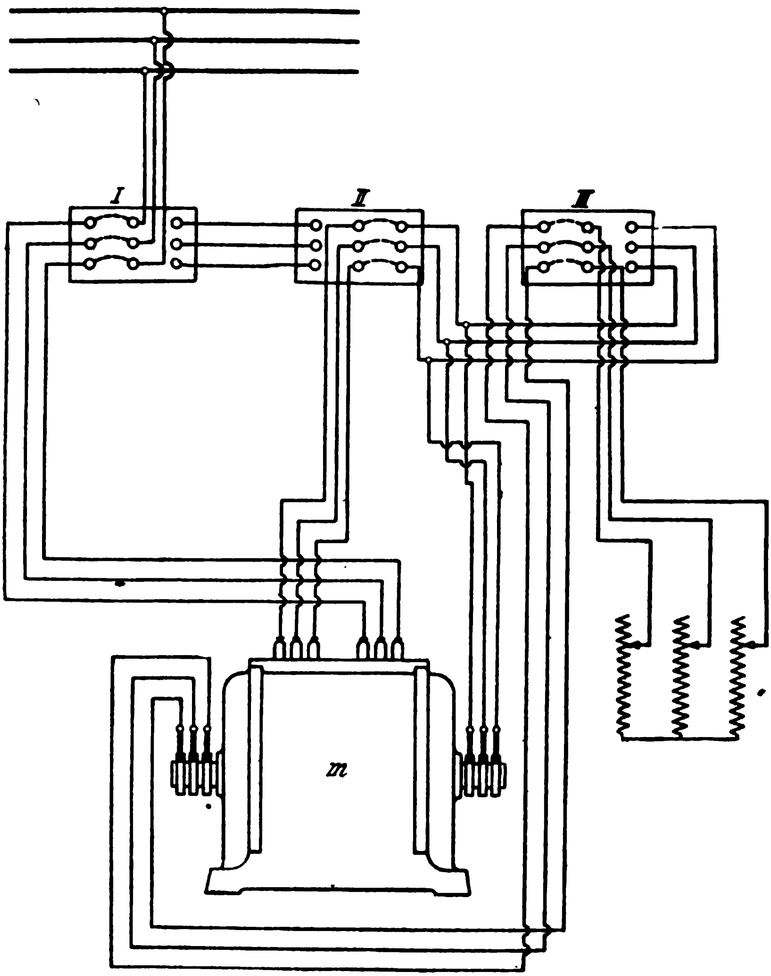

FIG. 3.

virtue of the positions they occupy on the stator. The general arrangement of the windings, as disclosed by the patent specification, is shown in Figs. 1 and 2.

In 1902 Mr. Lydall devised a cascade motor having independent

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primary and secondary stator windings wound for different numbers of poles. The rotor is similarly wound and provided with six slip rings. This machine does not depend upon the spacing of the stator coils to render the primary and secondary elements inductively independent of one another, but upon the choice of the numbers of the poles of the two fields. With this motor three efficient speeds are obtainable by changing the connections in the following manner: (1) With the first set of slip rings short-circuited, the motor runs as an "x" pole machine; (2) with the second set of rings short-circuited, the speed corresponds to that of a "y" pole motor; (3) with the first set of rings connected to the second stator winding and the second set of rings short-circuited, the speed is that of an "$(x+y)$" pole motor. Obviously result (3) could be obtained by connecting the two sets of slip rings and short-circuiting the second stator winding. Fig. 3 shows the system of connections as disclosed by the patent specification.

In 1903 Steinmetz took out a patent for a machine somewhat similar to the one devised by Thompson, the primary and secondary stator windings occupying alternate segments of the stator. The rotor carries independently short-circuited windings adapted to co-operate with the primary and secondary stator windings, as in the Thompson motor. The arrangement is such that they will also serve as ordinary non-cascade connected windings when the stator primary and secondary coils are connected in parallel. By the use of a throw-over switch the stationary windings can be so connected that the machine will operate either as an ordinary motor or as a cascade one. By these means two efficient speeds are obtained. The arrangement of the windings of this machine is shown in Fig. 4.

A German patent was granted in 1904 to Georges Meller for a disc type of cascade motor. In this machine the primary and secondary stationary windings are carried on separate stators in radial slots. Similar slots carrying windings are provided on both sides of the disc rotor, the windings on one side being acted upon by stator No. 1, those on the other side acting upon the windings of stator No. 2. The two sets of rotor conductors are connected together by means of connections carried across the outer circumference of the disc. The rotor is preferably divided into two parts in its vertical plane, and the machine is then exactly equivalent to two separate cascade-connected machines. The chief advantage claimed is the possibility of using very small clearances. Fig. 5 shows the general arrangement of this motor.

The machines already described, omitting the last, may be roughly divided into two groups, the first including motors depending upon suitable spacing of the stator windings to ensure non-interlinking of the two fields, and the second including machines provided with two stator windings wound for dissimilar numbers of poles.

The new motor, which has been developed by the Sandycroft Foundry Co., Ltd., belongs to the second group, the two numbers of poles being so chosen that when divided by their greatest common

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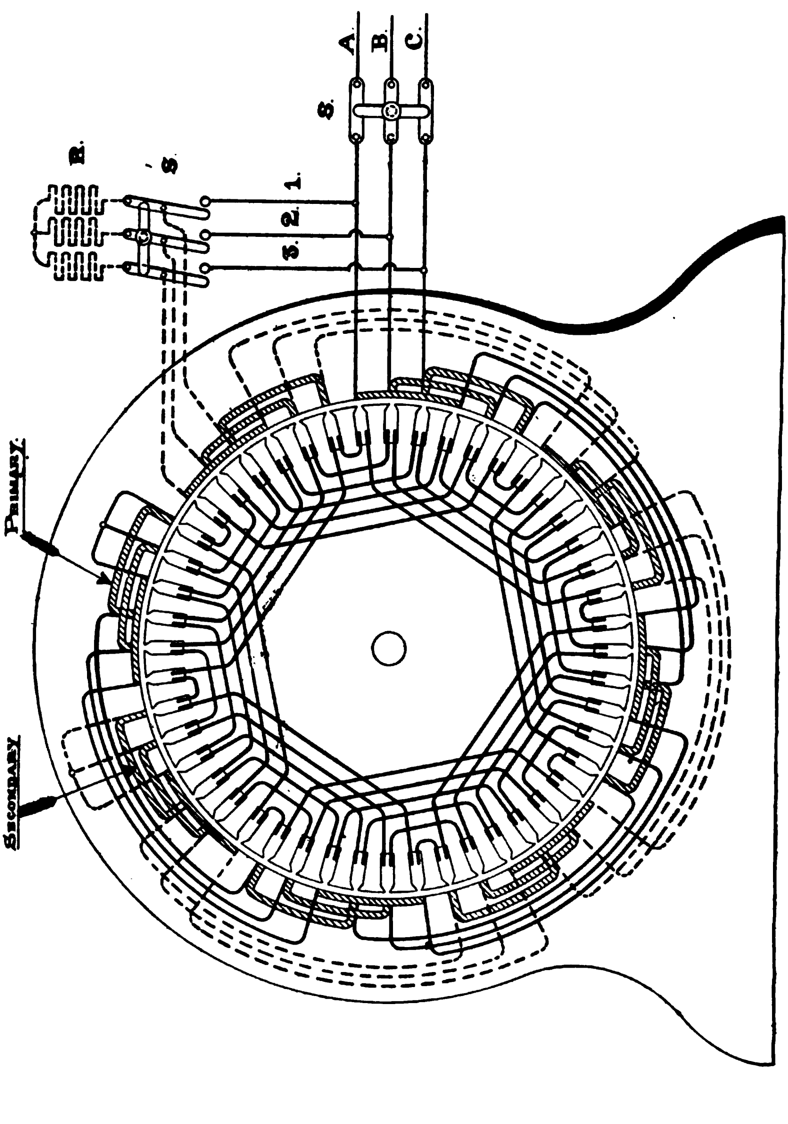

Fig. 4.

factor the quotient is in one case an even and in the other an odd number. This ensures non-interlinking of the two windings except by the agency of the rotor.

Fig. 6 shows the general arrangement of this motor, from which it will be seen that it closely resembles in design the ordinary type of machine.

The stator carries a single winding, and is provided with terminals for connecting to the supply mains, and with tappings which are connected in pairs through resistances whilst starting or when rheostatic speed control is desired, and are short-circuited at normal speed. The rotor, a photograph of which is shown in Fig. 7, is provided with a

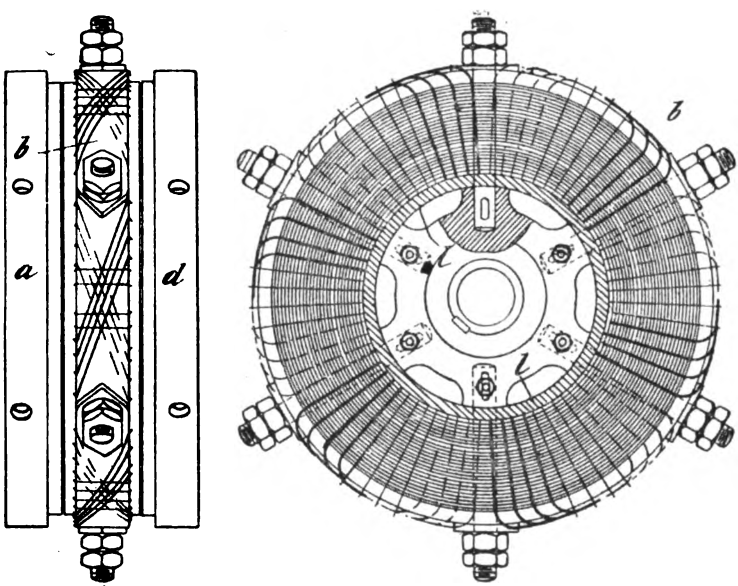

FIG. 5.

short-circuited winding without slip rings, unless designed to run at more than one efficient speed.

The chief difficulties to be overcome in the design of a "cascade" motor are greatly increased magnetic leakage and C^2R losses. Where two stator windings are used the inductance of the one occupying that portion of the slots farthest removed from the rotor is very large, owing to the increased leakage from tooth to tooth.

In experiments, which were made on a motor wound with separate 8-pole and 4-pole stator windings, the former being placed nearest to the rotor, it was found that the leakage per ampere-turn per inch length of core (after deducting the leakage of the end connections) was 7·0 in the case of the 8-pole winding and 11·4 in the case of the

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4-pole winding. The pole-pitch of the 4-pole winding was, of course, twice that of the 8-pole, and if the conductors had occupied the position of the 8-pole winding the leakage would have been certainly not more than 6·0 lines. By using one stator winding only, this difficulty was overcome, and experiments on the same motor showed that the power factor and overload capacity were much increased, although only two-thirds of the copper was used. The stator windings are parallel wound, and each pair of tappings connects two points of the winding

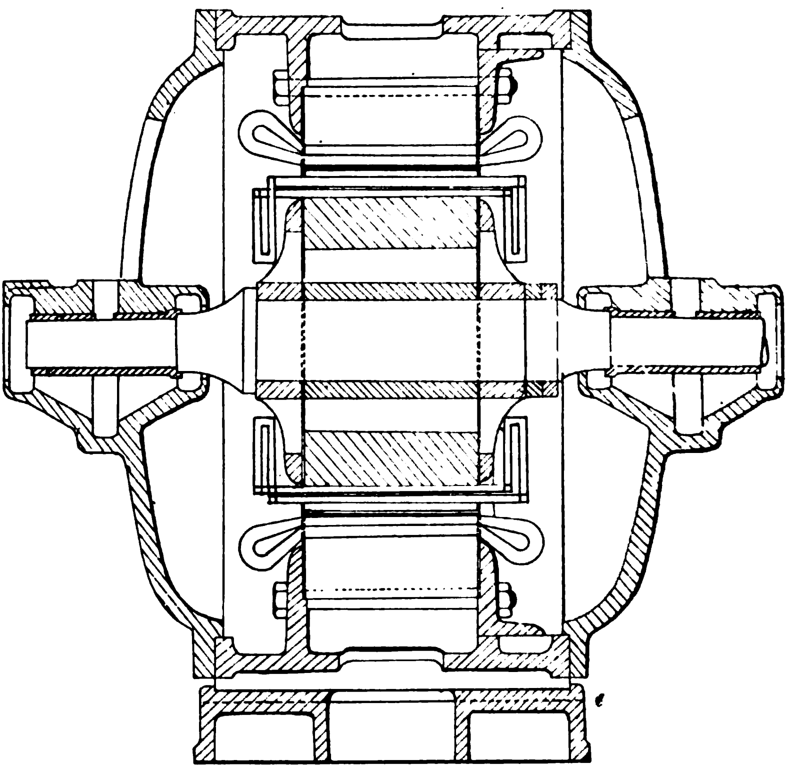

FIG. 6.

between which there is no "primary" difference of potential. Fig. 8 shows diagrammatically a 3-phase primary, 6-phase secondary stator winding.

The mains are coupled to the three terminals of the "star" and the starting resistances, arranged for 2-phase currents, are connected to the tappings A, A′ and B, B′. The remaining tappings are connected to a 4-pole switch mounted on the motor casing, and are short-circuited after the machine has reached its normal speed. This

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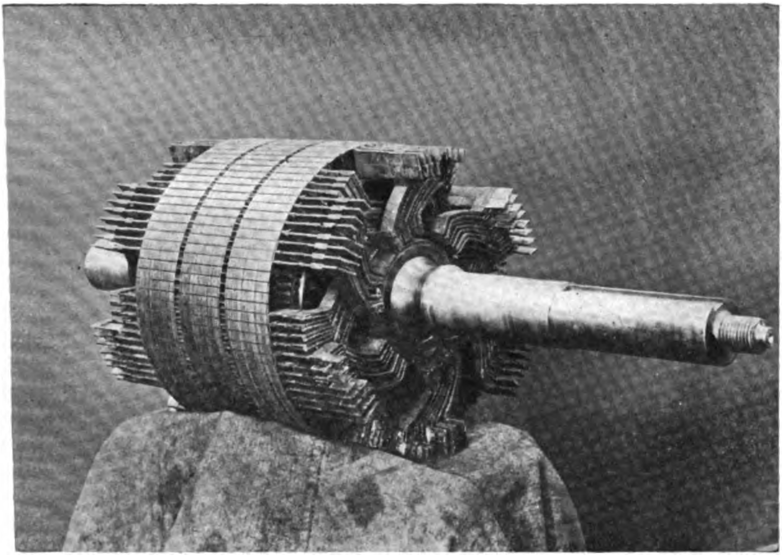

FIG. 7.

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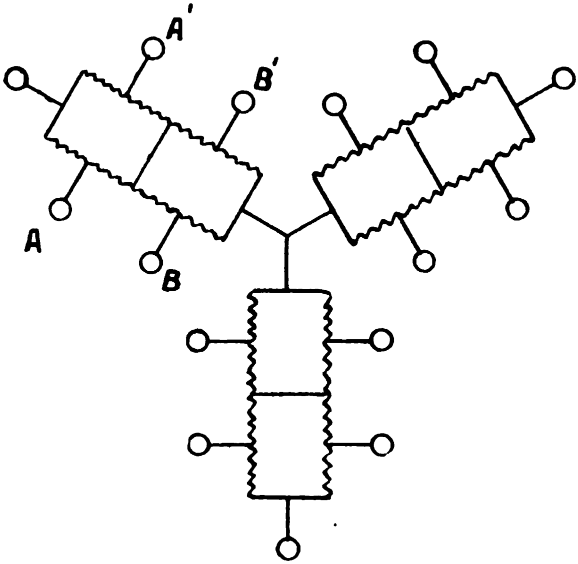

FIG. 8.

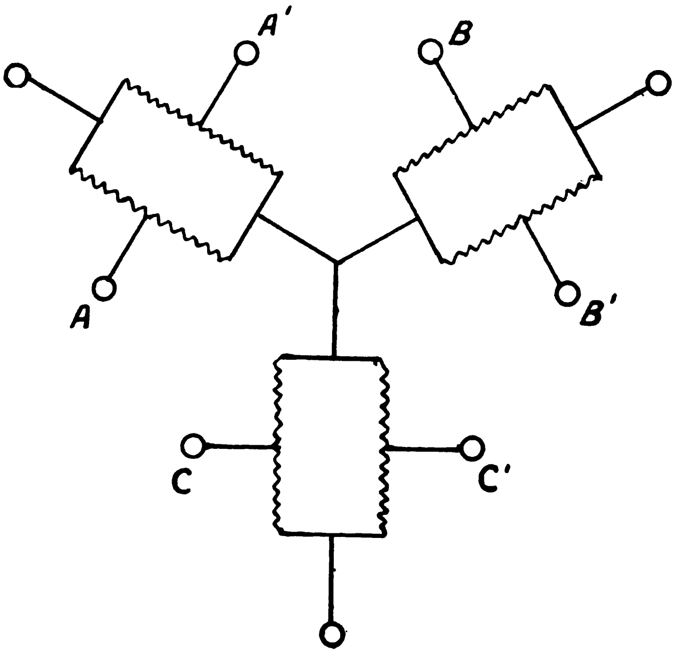

FIG. 9.

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winding, although involving the use of a short-circuiting switch, is preferred for constant speed motors, as the magnetic leakage and C^2R losses are rather less than would be the case if the windings were tapped for 3-phase currents only. The currents in each branch are in quadrature. The resultant stator current is equal to the geometrical sum of the primary and secondary currents, and may be anything in value between 1·07 and 1·2 times the primary current. The arrangement of the windings and the power factor of the motor determine the actual value of the current. In order to show how greatly the stator C^2R loss is reduced by using a single parallel wound winding instead of separate primary and secondary coils, the following table has been prepared. The machine is wound for 12 poles, the primary field having 8 and the secondary 4 poles.

For motors designed for variable speed work, with rheostatic control, it is preferable to tap the stator windings for 2- or 3-phase secondary currents in order that the whole of the windings may be active during the time when the tappings are not short-circuited,

	Stator Wound with Separate Primary and Secondary Windings.	Stator Wound with a Single Tapped Winding.
Size of slots	$1\frac{1}{4}$ in. × $\frac{11}{32}$ in.	$1\frac{1}{4}$ in. × $\frac{11}{32}$ in.
Number of Slots	72	72
Number of primary conductors, per coil	2	2
Number of secondary conductors, per coil	2	—
Cross section of each primary conductor (sq. mm.)	15·75	13·25 × 2 = 26·5
Cross section of each secondary conductor (sq. mm.)	6·75	—
Primary current	62 amps.	62 amps.
Secondary „	27·0 „	—
Resultant „	—	73 amps.
Current density in primary winding (amps. per sq. mm.)...	3·93 „	2·75
Current density in secondary winding	4·0 „	—
Mean length of one primary turn	34 ins.	34 ins.
„ „ secondary „	50 ins.	—
Total length of primary winding...	408 ft.	408 ft.
„ „ secondary „ ...	600 ft.	—
Resistance of primary windings (hot)	0·155 ohms	0·088 ohms.
Resistance of secondary windings (hot)	0·54 „	—
Primary C^2R losses (hot)	595 watts	468 watts
Secondary „ „	393 „	—
Total Stator C^2R losses	988 „	468 watts
Total weight of Stator Copper ...	62·3 lbs.	64·6 lbs.

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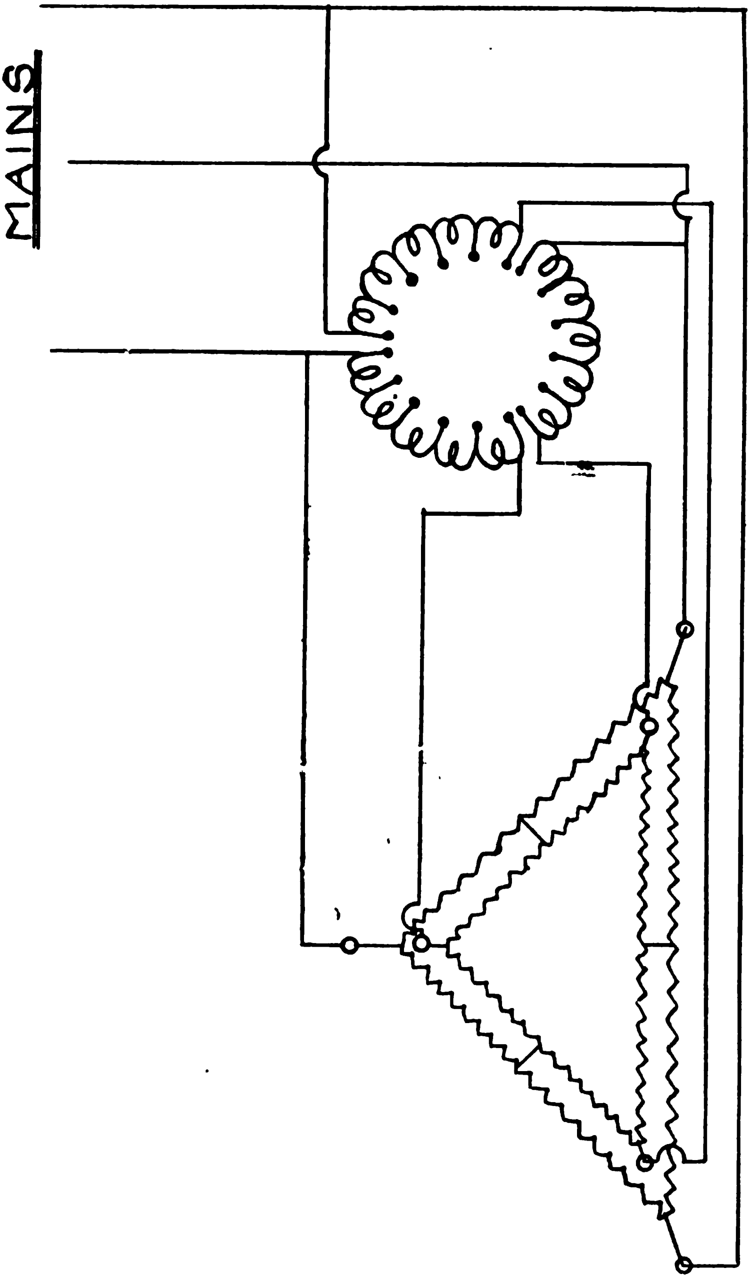

FIG. 10.

Fig. 9 shows diagrammatically a suitable winding for this purpose. The tappings A, A′; B, B′; C, C′ are connected to three independent resistances.

Another form of winding, "mesh" connected, is shown in Fig. 10, arranged for 3-phase tappings. This requires only six terminals as

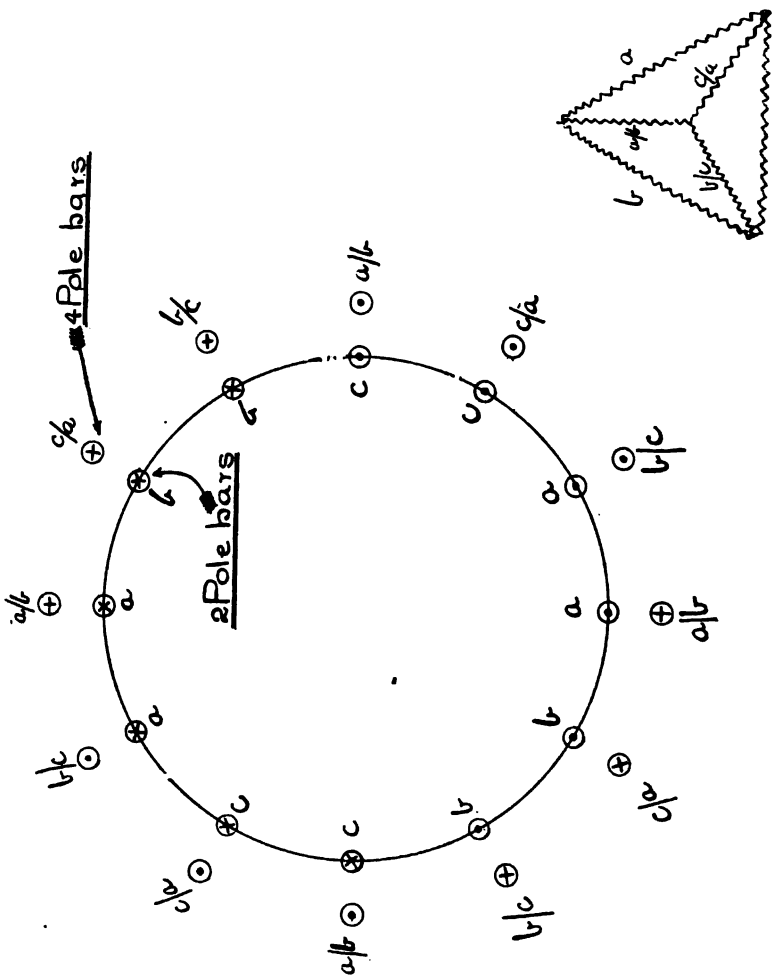

Fig. 11.

three are common to both primary and secondary currents. The whole of the stator windings are not, however, active until the tappings are short-circuited.

Referring now to the rotor, a large number of different methods of winding are possible. It is important to keep the rotor C^2R losses as

small as possible in order to ensure a high efficiency, and also to reduce the drop in voltage between the primary and secondary parts of the machine. The voltage drop has an important bearing on the performance of the motor as, omitting consideration of the inductance, the magnitude of the second flux depends upon it. If the C R drop be large the overload capacity will be prejudicially affected.

The rotor may be provided with two separate windings, one wound for "x" number of poles and the other for "y" number of poles, the

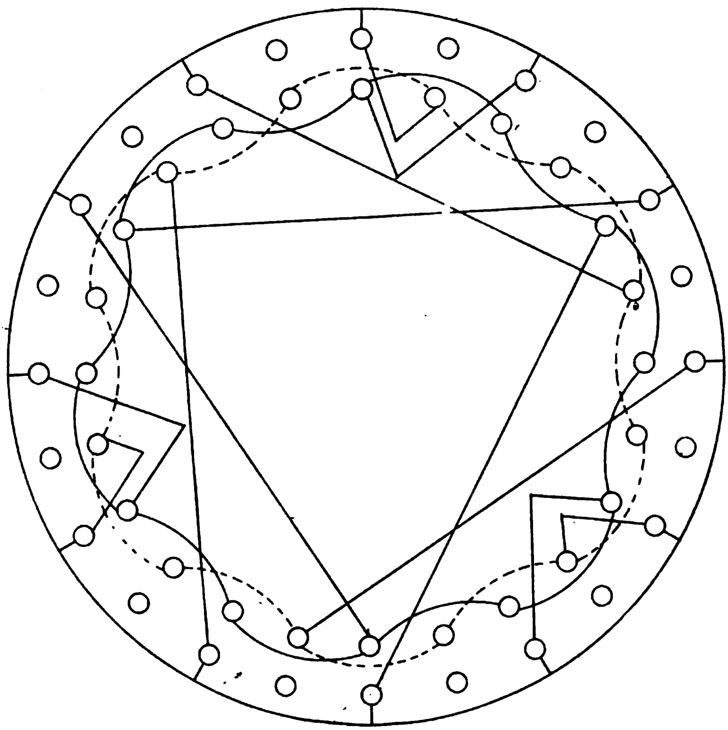

FIG. 12.

two being inter-connected. In this case the currents induced in the "x" pole winding flow into the "y" pole conductors, and produce the second magnetic field. It may be here stated that the objection raised to the two separate stator windings does not apply to the rotor, as the frequency of the currents is the same in both rotor windings. In fact, the local leakage lines are due to the resultants of the currents in the two sets of conductors, and by suitable arrangement the total inductance of the two windings may be made less than the sum of the inductances considered separately. Fig. 11 shows a rotor having two windings, one

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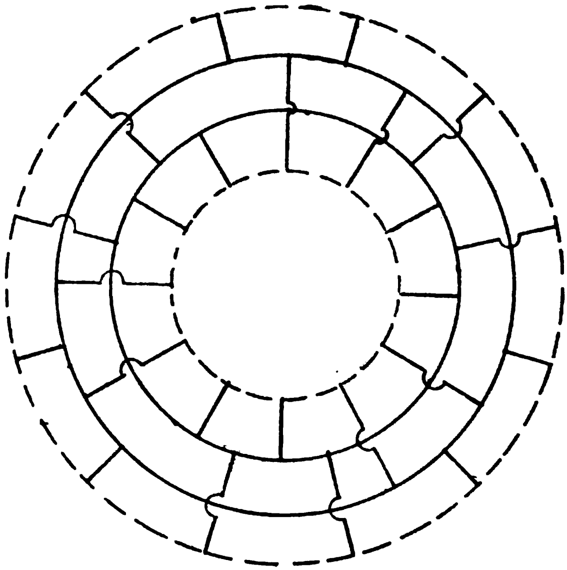

FIG. 13.

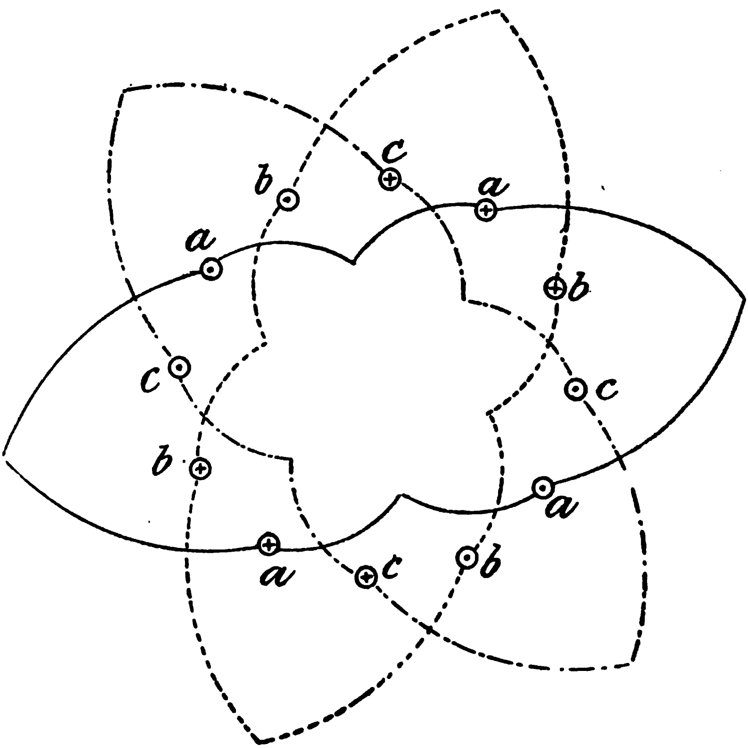

FIG. 14.

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connected for 4 poles and the other for 2 poles. The former is "star" and the latter "mesh" connected. The 4-pole ampere-turns are consequently equal to 1·73 times the 2-pole ampere-turns. Only one slot per pole per phase is shown in the diagram.

Instead of grouping the bars in two separate 3-phase windings, the 4-pole and 2-pole conductors may be connected to form a winding, as shown in Fig. 12.

This arrangement reduces the length of copper required in the end connections, and has the same effect as two separate windings. The

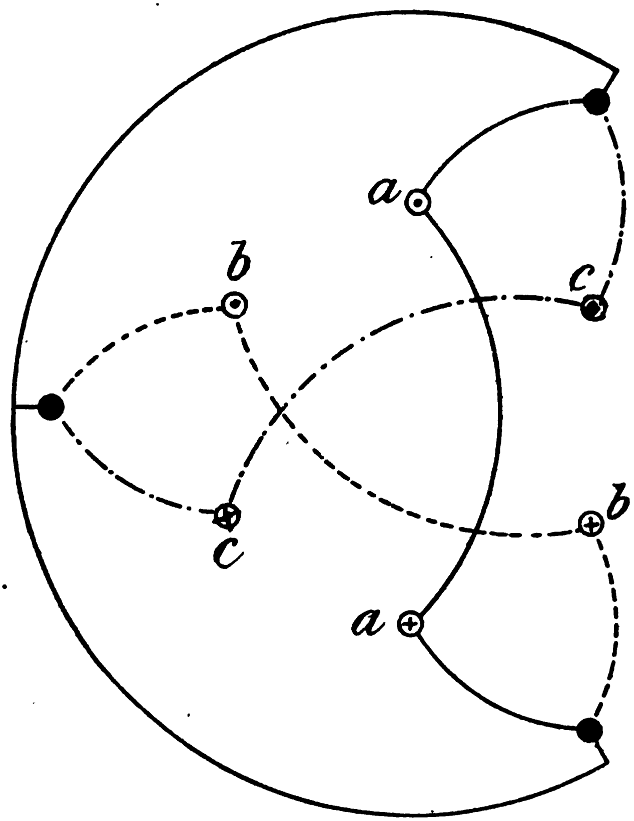

FIG. 15.

2-pole bars are connected to form two "mesh" windings, as shown. Each 4-pole bar is connected at one end to a 2-pole bar, and at the other to a short-circuiting ring. There are two of these rings, one at each end of the rotor. Only the connections at one end of the rotor are shown. Those at the opposite end are duplicates of these. The outside circle represents one of the short-circuiting rings. The inner ring

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of small circles are the 2-pole bars, the outer ring the 4-pole conductors. Fig. 13 shows this winding diagrammatically. The dotted circles are the short-circuiting rings and the full-line ones the "mesh" connected 2-pole conductors. Each radial line represents a 4-pole bar.

A (4 + 2) pole winding has been shown, but it may be mentioned that as the resultant magnetic field is not symmetrical, a motor having this number of poles is not satisfactory. If, however, diagrams had been prepared for a larger number of poles they would have been confusing when reduced to a small scale.

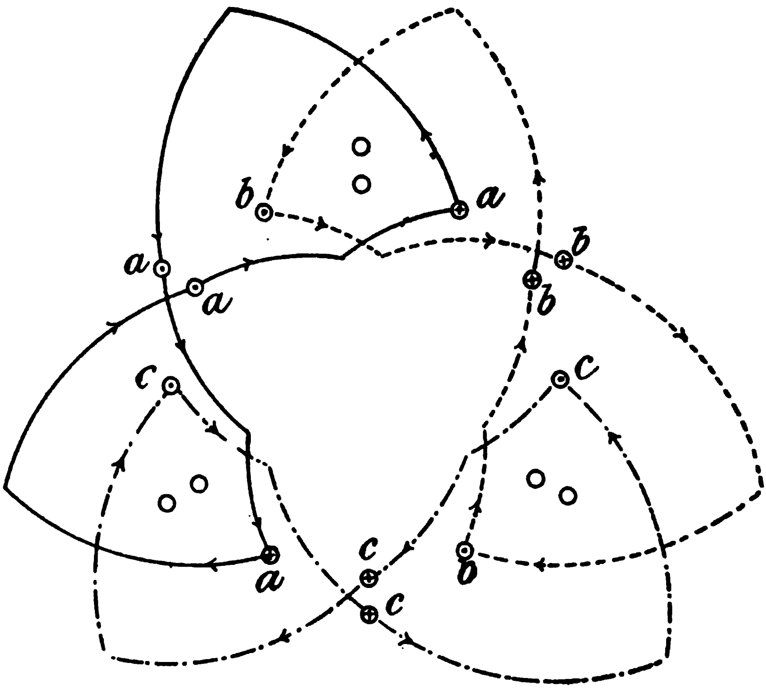

FIG. 16.

It has already been mentioned that the currents of the two rotor windings in any one slot may be algebraically added together and considered as one current. By a suitable arrangement of the connections one winding may therefore be substituted for the two, and the total C^2R losses reduced to that of the "x" pole winding only. Figs. 14 and 15 show the directions of the currents in 4-pole and 2-pole windings at the instant when the current in the "a" phase is equal to m, and those in the "b" and "c" phases to $\frac{m}{2}$. Two pole bars occupy only one-half of the slots.

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By super-imposing one diagram upon the other it will be seen that some of the currents cancel one another. The resultant diagram is shown in Fig. 16.

The number of conductors and the total length of the end connections are equal to those of the 4-pole winding only. On the score of low copper loss this is a very good winding, but it has two serious faults; the slots are deep owing to the concentration of the conductors,

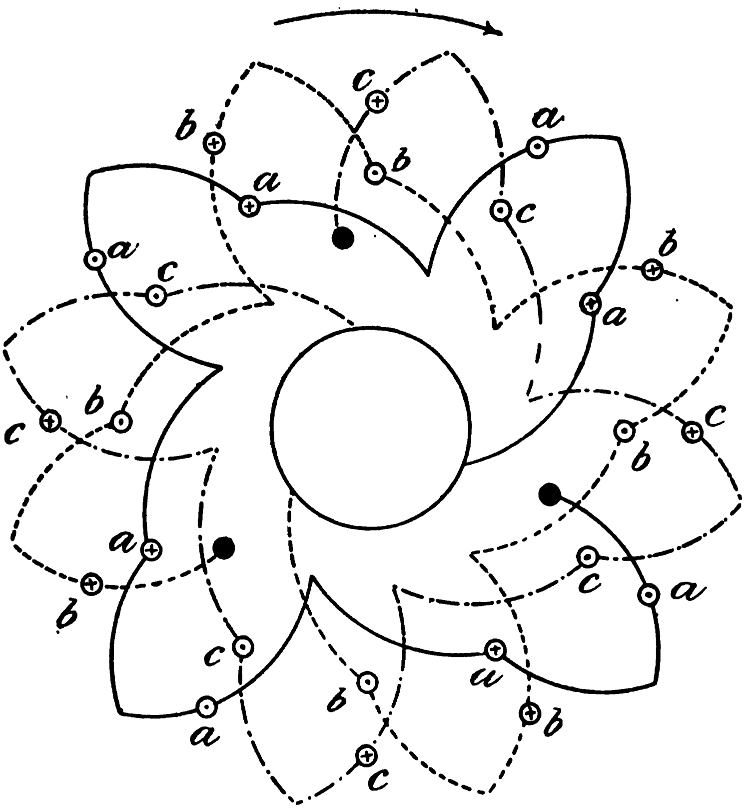

FIG. 17.

and the inductance, for the same reason, is considerably higher than that of the windings already described. Experiments were made with a small 12-pole motor, the rotor of which was provided with double windings similar to those shown in Fig. 11. After tests had been made, it was rewound with a single winding as shown in Fig. 16. The double winding gave a power factor of 0·78 and the single winding 0·72. These results were obtained with a double wound stator. The 8-pole stator winding was then re-connected and provided with 6-phase

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tappings, and further tests showed a rise in power factor from 0·78 to 0·81. The efficiency was, of course, higher with the single than with the double rotor winding. One may extend the list of resultant windings indefinitely, but one further example will serve for the purpose of this paper. Figs. 17 and 18 show 8-pole and 4-pole windings. The one shown in Fig. 18 is, strictly speaking, a 6-phase

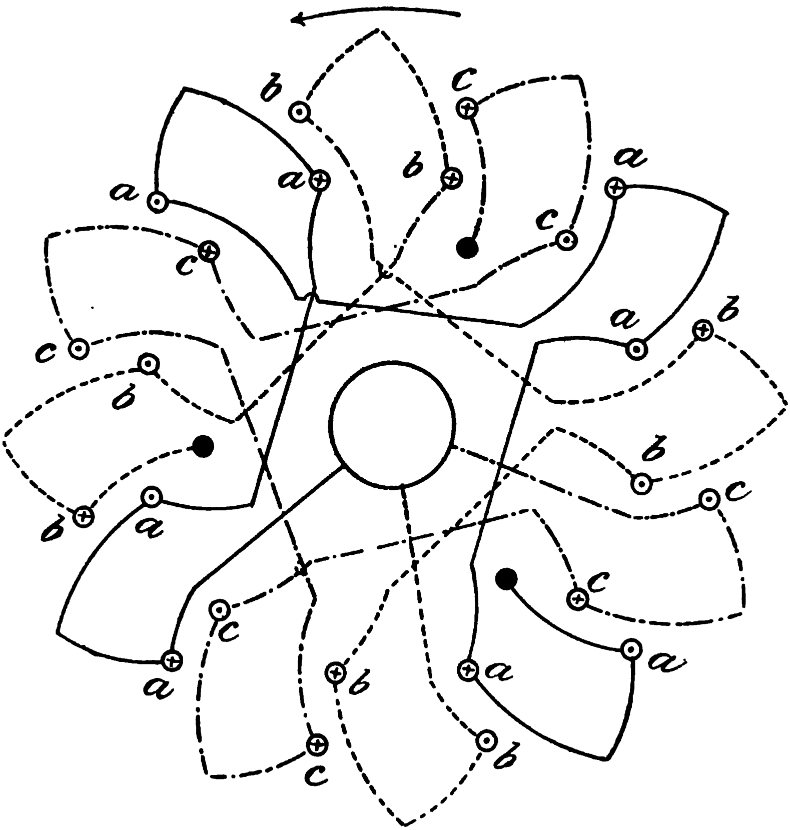

FIG. 18.

winding, as there are six groups of conductors per pair of poles. The winding shown in Fig. 17 has only three groups of conductors per pole pair, each group being made up of currents belonging to two different phases.

The resultant current in any one pair of bars of the 8-pole winding equals 1·73 times the current in one bar. By super-imposing Fig. 17 on Fig. 18 the resultant winding, Fig. 19, is obtained, in which the currents

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are of the same phase in each slot. The winding is a simple non-overlapping one.

Tests on windings of this type gave results very similar to those obtained with the single winding shown in Fig. 16. The power factor was found to be not so high as that given by the less simple forms.

The rotor windings already described are suitable for motors having one efficient speed. Motors are being manufactured which may run at two, three, or four efficient speeds, and it is clear that as these require

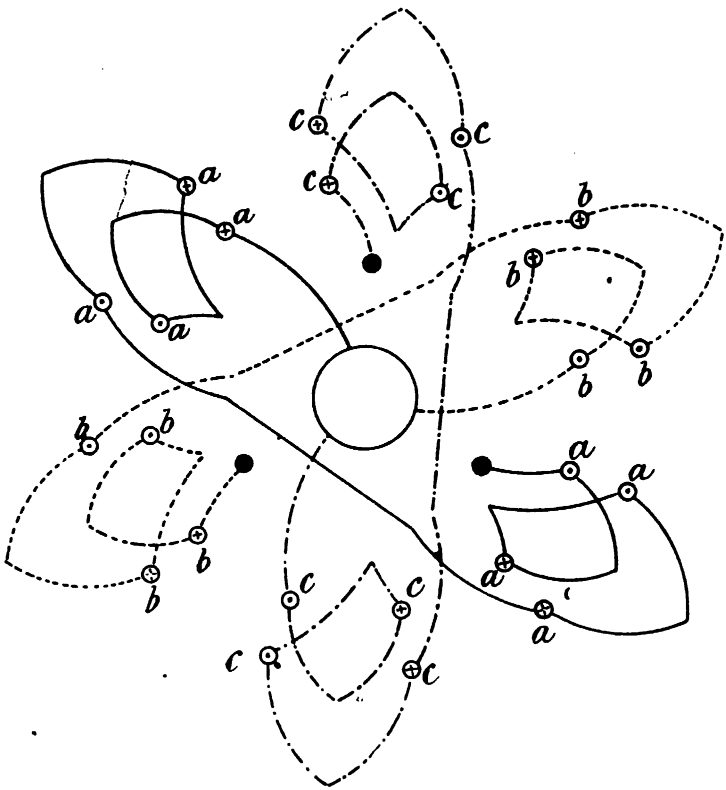

FIG. 19.

the addition of slip rings, the number of phases for which the rotors may be wound must be limited to two or three.

A 12-pole motor having a rotor carrying 8-pole and 4-pole windings may, if fitted with three slip rings, be run at speeds corresponding to 12, 8, or 4 poles without losses in resistances. For a two-speed motor the connections are very simple, and especially is this the case if two rheostats are used. Fig. 20 shows diagrammatically the stator and rotor windings where the latter are of the type shown in Fig. 11.

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If the motor be wound for 8 and 4 poles and the periodicity be 50 cycles per second, the two efficient synchronous speeds will be 500 and 750 revolutions per minute. The "mesh" connected rotor windings are wound for 4 poles and the "star" windings for 8 poles. Slip rings are connected to the three terminals shown. The three stator terminals are connected to the mains, and the tappings are coupled in pairs by three resistances. As these resistances are cut out of circuit the motor

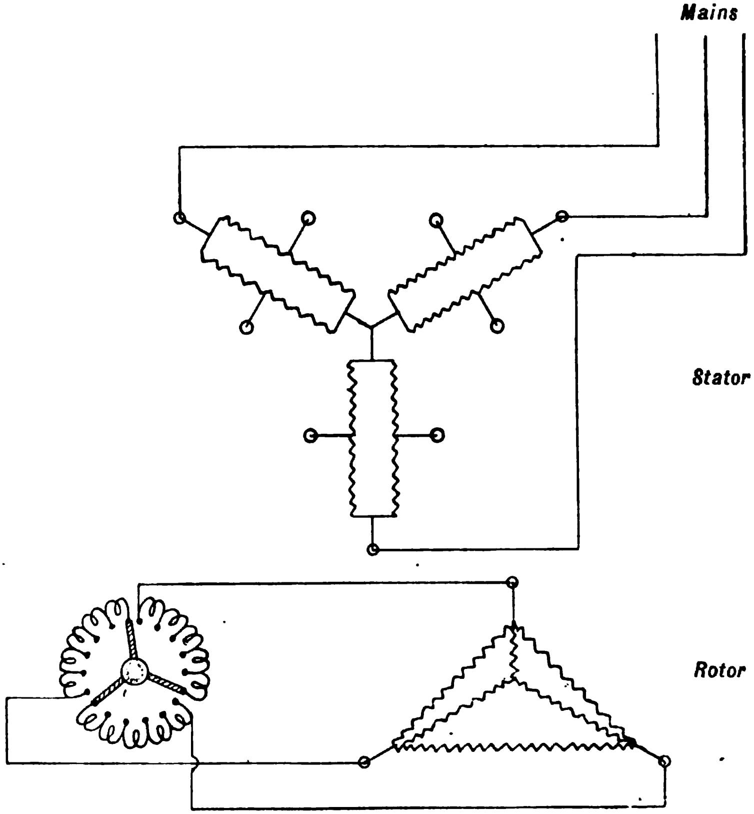

FIG. 20.

speeds up until, with the tappings short-circuited, it reaches a speed approximating to 500 r.p.m. The three slip rings are now connected through resistances, and as these are cut out of circuit the motor speed increases until it reaches 750 r.p.m., with the rings short-circuited. No current now flows through the stator tappings or into the 4-pole rotor winding. The motor will give an increased output, as the iron losses are less then when cascade-connected, and the copper losses are also much reduced.

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An alternative form of rotor winding is one similar to that shown in Fig. 16, but with all the slots filled with conductors. The additional bars are connected to form a "star" winding, the terminals of which are attached to slip rings.

In order to obtain three effective speeds a change-over switch is necessary in the stator circuit. This enables the connections to be changed so that the primary currents may produce either an 8-pole or a 4-pole magnetic field. When connected for 4-poles, and with the slip rings short-circuited, the motor runs at a speed of 1,500 r.p.m. The 8-pole rotor winding is now inoperative.

By the use of five slip rings, the rotor connections may be changed so that both magnetic fields rotate in the same direction. The motor then runs at a speed corresponding to that of a machine wound for a number of poles equal to the difference between the numbers of poles of the two magnetic fields. For example, if the motor be wound for 12 and 8 poles, and used on a 50-cycle circuit, the following speeds can be obtained: 300, 500, 750, and 1,500 r.p.m.

If continuous, as well as alternating currents, be supplied to the stator windings, the motor runs at synchronous speed. The continuous-current leads may be taken to the tappings of one of the phases of the winding, or a parallel star winding may be used. In the latter case the continuous-current leads would be connected to the two neutral points of the "stars." The machine is started up as an induction motor, and when it has reached normal speed the continuous-current switch is closed. The motor pulls into step, no synchronising gear being necessary. There is no difficulty in starting against load.

The motor exhibited here to-night is a small twelve-pole one-speed machine, the magnetic fields being eight and four pole. It gives an output of 12·5 B.H.P. at a speed of 490 revolutions per minute when supplied with 50-cycle current. The outside diameter of the rotor is 14 ins., and the stator has 72 slots. There are consequently three slots, and six slots per pole per phase in the 8-pole and 4-pole parts of the machine respectively. The stator winding is of the type shown in Fig. 8, and the starting switch is arranged for 2-phase currents. The rotor carries a 12-phase winding, and there are equal numbers of 8-pole and 4-pole bars. The 4-pole conductors are connected to form two "mesh" windings. To the junction of each pair of 4-pole bars is connected an 8-pole bar, and alternate bars are connected to the "mesh" windings at opposite ends of the rotor. At each end of the rotor is a short-circuiting ring, to which alternate 8-pole bars are attached. The 8-pole conductors are consequently "star" connected, and the ratio between the currents in the 8-pole and 4-pole bars is therefore approximately 2 : 1. The winding is similar to that shown in Figs. 12 and 13, but is 12 instead of 6-phase. I regret that I am unable in this paper to give detailed test figures of these new motors, but several machines are nearing completion, and results of tests will shortly be published in the technical press.

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Discussion.

Mr. Field.

Mr. M. B. Field: On the first page the author refers to the "cascade" system of connection, where the rotor of one motor is connected to the stator windings of a second motor, the rotor of the second motor being connected in its turn to starting resistances, which are ultimately short-circuited when the combination has run up to speed. As I understand the "cascade" system, it is necessary that the motors be mechanically as well as electrically coupled—a point which Mr. Hunt has omitted to mention.

The author states that if the machines have the same number of poles, and the windings are connected so that their magnetic fields rotate in opposite directions, the synchronous speed of the combination will be half the natural speed of either motor. I am unable to account, both here and later on, for the directions of rotation which Mr. Hunt requires. For example, in Fig. A below, suppose both machines are bipolar and the rotors are belted together. Let the stator of one be supplied with 3-phase current at a frequency of N cycles per second. Being bipolar, the magnetic field generated by the stator winding in motor No. 1 will rotate, let us say, clockwise, at N revolutions per second.

Suppose the rotor is also rotated clockwise $\frac{N}{2}$ revolutions per second, the relative slip between field and rotor will be likewise $\frac{N}{2}$ revolutions per second. The frequency of the induced currents in the rotor will be $\frac{N}{2}$. These currents are led into the stator of No. 2 machine so that the stator field of No. 2 machine will rotate with a speed of $\frac{N}{2}$ revolutions per second. The two rotors being mechanically coupled, that of No. 2 will obviously rotate in the clockwise direction with a speed of $\frac{N}{2}$ revolutions per second, and there will be no slip, *i.e.*, synchronism will be attained if the stator windings of No. 2 are so connected to the rotor windings of No. 1 that the stator field of No. 2 is rotated in the clockwise direction. We, therefore, have a synchronous speed of half the natural speed of either motor when the magnetic fields in both No. 1 and No. 2 are rotated in the same direction as indicated by the arrows, and not in opposite directions.

My next difficulty was still at the bottom of the first page. Mr. Hunt says that if the motors have a dissimilar number of poles and be connected so that their fields rotate in the same direction, the speed of the combination will be equal to the difference of the independent speeds. He gives as an example a 2-pole and a 6-pole combination, and says that this will run at the speed of a 4-pole machine, which statement does not correspond with the previous one. Further, on page 650, he gives an example of an X-pole and a Y-pole combination, which runs at a speed of an X + Y-pole motor, which, again, does not correspond to either of

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Mr. Field.

the previous statements. Suppose, for instance, we take a 2- and a 6-pole combination, the frequency being 50. The speed of the 2-pole motor would be 50 revs. per second; that of the 6-pole motor 16⅔rds revs. per second. The difference between these two is 33⅓rd revs. per second, but a motor having a difference of the number of poles, viz., 4 poles, would run at 25 revs. per second; whereas, taking the example on page 650, the combination would run at 12½ revs. per second.

I think these discrepancies are more a question of the author having expressed himself ambiguously, and of my having put upon his phrases a different meaning from that which he has in his own mind. I have puzzled a good deal, however, to find what other interpretation one can put upon his phraseology, and I have not come to a satisfactory solution.

Taking the case of a "cascade" system with a dissimilar number of poles, the synchronous speed may be determined as follows: Let No. 1 motor have p_1 North poles and No. 2 motor have p_2 North poles. Let the frequency of the supply current of the stator of No. 1 be N. The speed of the rotating field of No. 1 will then be $\frac{N}{p_1}$ revs. per second, which we will assume to be in the clockwise direction. We can imagine the rotor running either clockwise or counter-clockwise. We will, therefore call its speed $+$ or $-m$, the plus sign being taken for clockwise direction and minus for counter-clockwise. The relative slip of magnetic field and rotor will then be $\frac{N}{p_1} \mp m$ revs. per second. The frequency of the induced currents in the rotor of No. 1 machine is $N \mp m p_1$, and these currents are led into the stator of No. 2, which has p_2 North poles, and therefore the field rotates in No. 2 with a speed of $\frac{N \mp m p_1}{p_2}$.

Now, the rotor of No. 2 being mechanically connected to that of No. 1 rotates with a numerical speed of m revolutions, and, of course, the stator of No. 2 must be so connected that the field rotates in the same direction as does the rotor. If this were not done, synchronism would be impossible, but given this condition, synchronism will be attained when the numerical speed of the stator field No. 2, or $\frac{N \mp m p_1}{p_2}$ is equal to the numerical speed of the rotor, which is m. This gives the condition that the synchronous speed, m, is equal to $\frac{N}{p_2 \pm p_1}$.

Now, it will be seen that this expression agrees both with that given on page 648, where the difference in the number of poles is taken as determining the speed, and on page 650, where the sum of the number of poles is taken as determining the speed of the combination, provided we start out with the proper direction of rotation of the magnetic fields, but the rotation, as I understand it, is just the reverse of what Mr. Hunt gives.

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Mr. Field. In Fig. A, let us assume, as an example, that motor No. 1 is 2-polar; motor No. 2 is 6-polar.

Now, if the magnetic fields in the two motors rotated in the same direction, *i.e.*, clockwise, as shown in the figure, according to the above formula, the speed of rotation should be that of an 8-pole machine, not a 4-pole machine, and this certainly appears to me to be correct. Currents with frequency N are led into the stator of No. 1 The winding being 2-pole, the stator field rotates at N revs. per second. Suppose that the rotor is rotating clockwise at $\frac{N}{4}$ revs. per second, the slip between stator field and rotor will be $\frac{3N}{4}$ revs. per second, and this will also be the frequency of the induced currents. The rotor of No. 2, being mechanically connected on to that of No. 1, runs clockwise at a speed of $\frac{N}{4}$, and in order for there to be no slip, the stator of No. 2 will have to be connected for a clockwise rotation of its field. The

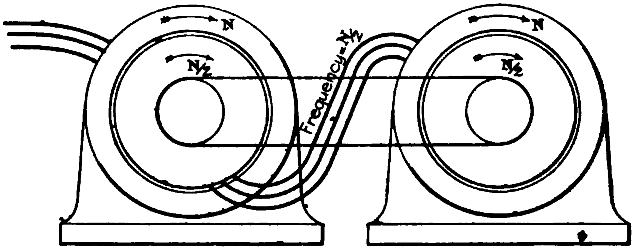

FIG. A.

frequency of the rotor currents of machine 1, as above stated, is $\frac{3N}{4}$ and these going into a 6-pole winding will give a speed of rotation of the stator field of $\frac{N}{4}$, which exactly corresponds to that of the rotor, which is, therefore, synchronous speed. Similarly, if we assume that the rotor of No. 1 is rotated counter-clockwise, that of No. 2 will rotate counter-clockwise, and the stator of No. 2 will have to be so connected that its field rotates counter-clockwise, and we shall find that synchronism is attained when the speed of the rotors is $\frac{N}{2}$. Hence, it appears to me that when the two stator fields rotate clockwise, the synchronous speed corresponds to a combination having 8 poles total, and when the two stators are so connected that the fields run, one clockwise and one counter-clockwise, the speed of the combination will be equivalent to a machine having a total of 4 poles.

My next question is, what is the object of the "cascade" system when applied to a 1-speed machine? I was always under the impression that the essence of the "cascade" system was to obtain two efficient

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speeds at least. Mr. Hunt has clearly indicated the very great disadvantages of the "cascade" system, owing to the large magnetising current, bad power factor, big copper losses, large weight of material for the output, and so on, and I have always looked upon the question as a compromise between the advantages of a 2-speed machine and the above enumerated disadvantages; but what is to be said in favour of a 1-speed cascade-connected machine, such as that described on the last page of the paper? Is it in any way a better machine than a 12-pole ordinary straightforward-wound motor? Is the only advantage that the slip rings of the rotor are eliminated, and, if so, is the machine substantially better than a 12-pole squirrel-cage motor? There are no tests in the paper to give us any clue as to the answer to this question, and it certainly seems a great complication if the sole object is the elimination of the rotor's slip-rings. Mr. Field.

With regard to the "cascade" system for the multiple-speed motor, it almost seems to me that we are trying to make a motor do something which it is, by the very nature of things, most unsuited to do. An alternating-current motor of this description has one definite speed at which it wants to run. At that speed we have best power factor, best efficiency, best output for the weight, best performance altogether. If we try to make it run at any other speed, we have to put up with great sacrifices. It is not like a series continuous-current motor. It is not even like a shunt continuous-current motor; but there is something in its nature by which it prefers its one particular speed, and offers the very greatest objections to going at any other pace. This being so, is not the proper solution of the problem merely a mechanical one, and not an electrical one? Is it not a question of getting a suitable change-speed gear to attach to the motor, more especially for the smaller sizes? In view of our experience in motor-car work, it seems to me that this is by no means an impossible solution. No doubt up to the present the gearings which have been tried have been unsatisfactory, but so have the electrical devices for the solution of the same problem, and the mere fact that no suitable mechanical gearing has been devised so far is no proof that this is not the proper solution. If it could be arranged that the motor drives a secondary shaft with two or more idle running spur-wheels mounted on the latter with suitable multiple disc clutches so as to render any idle running spur-wheel fast with the counter-shaft, immersing the whole in an oil bath, we should have this great advantage: that the motor was always running at its best speed, obtaining the best use of its material, and that when the countershaft was running at its lowest speed we obtain a proportionately increased torque, *i.e.*, the combination is always giving its full power.

With the "cascade" system, as far as I am aware, the torque is not increased at the lower speeds, hence, if the combination runs at half the maximum speed it can only develop one half of the maximum total capacity.

It must be remembered that one of the members of the "cascade"

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Mr. Field. combination works to a large extent as a frequency changer. For instance, take the case of the 2- and 6-pole combination running at the 4-pole speed. The rotor of No. 1 is running in the opposite direction to the stator field, *i.e.*, it is absorbing power, and is actually being driven by No. 2. The introduction of this frequency-changer, absorbing power as it does, appears to me very like putting in a transformer to transform from 200 volts to 100 volts in order to supply a motor with current, instead of arranging the windings of the motor to take 200 volts direct.

The question of the interlinking of a winding of one number of poles with a field of another number of poles is interesting. Mr. Hunt states that in order to give satisfaction the numbers must be so chosen that when divided by the greatest common factor, the quotient in the one case must be an even number, and in the other case an odd

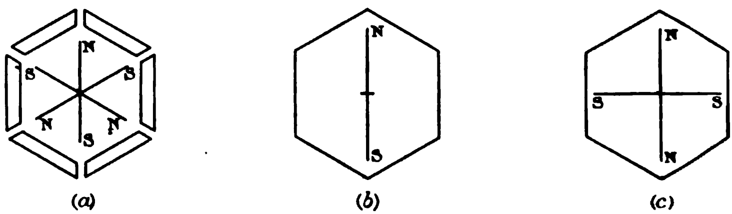

Fig. B.

number. On page 662, however, he states that a 4- and a 2-pole winding does not give satisfaction, although it is to be noted that according to the rules stated on page 653, and above quoted, the 4- and the 2-pole windings should not reduce interlinking. It appears, therefore, that this rule is not the only one determining the relative number of poles to ensure satisfaction. This question of interlinking may be exemplified very simply in the following way :—

In Fig. B the hexagon represents six coils of a 6-pole winding. If we imagine a 6-pole magnet system rotating within this winding, an E.M.F., of course, would be generated (see Diagram *a*). If we strike out two pairs of poles as in *b*, we shall obviously generate one-third of the E.M.F. Here we have a 2-pole magnet system interlinking with a 6-pole winding. The ratio of these numbers is 1 : 3, *i.e.*, both are odd numbers. In order to ensure that the arrangement shown in *b* shall not produce any E.M.F., it will be necessary to reverse the South pole and make this into a North pole. This North pole would produce just the reverse effect of the other North pole. Having two North poles, we naturally require two South poles somewhere. These are shown in Diagram *c*. Obviously these two South poles would similarly neutralise each other's effect, so that the arrangement in *c* will produce no E.M.F. This is a 4-pole magnet system in a 6-pole winding, the ratios being 2 : 3, that is, an even and an odd number.

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Mr. H. W. Wilson: I should like to point out that assuming Mr. Hunt obtained the results which he has taken more or less for granted in the paper, a motor of the type described would be a very great convenience. The difficulty with alternating-current working from a practical point of view is, of course, variable speeds. Variable speeds of any wide range are difficult to obtain, and although slip-ring motors can be used with regulating resistances, that is not a very satisfactory or economical method of working, and a machine of the type shown appears to me to fill somewhat the same position that a double commutator machine does in direct-current working. It gives a very large range of speed variation, with fairly efficient running. I am assuming, of course, that in between the efficient speeds we can get other speeds by the use of regulating resistances in the ordinary way. The point upon which I am not clear is this: In one place certain power factors are mentioned which have been obtained by experiment. Of course the machine in question is only a small one, and very high power factors cannot always be obtained. Has the author made any calculations of the power factors of fairly large machines, and can he give us any ideas of efficiencies of machines of this type at various speeds; is the efficiency fairly constant over all speeds, or is it variable? Mr. Wilson.

The next point I should like to ask about is, assuming that the machines give the results hoped for, is the cost going to be very high, because that really is the most important consideration with all special machines. If the cost is going to be prohibitive, then they are very interesting inventions, but not of much practical use. The machine shown does not look particularly complicated to make.

I am at one with Mr. Field in wanting to know what is the use of the special type of winding for a machine with one speed. When I saw the switch on the top of the machine I came to the conclusion that the machine does run at two speeds, but Mr. Hunt had stated that it is really wound for one speed, and I should like to know what is the function of the switch at the top.

Mr. L. J. Hunt (*in reply*): With regard to Mr. Field's remarks referring to the "Cascade" system of coupling two motors I must plead guilty to an error in the general statement as applied to two separate motors. The principle of the system was only briefly referred to in a very general way as so much has been recently written on the subject in connection with the theory of motor converters. The remarks as to relative directions of rotation of the two magnetic fields is strictly correct when applied to the "Cascade" motor or to two machines, the rotor windings of which are inter-connected. When the rotor windings of one motor are connected to the stator windings of the second motor the conditions are obviously reversed. I do not understand Mr. Field's difficulty with regard to the statement in the paper where it is remarked that with the two elements coupled in "Cascade" the speed will correspond to that of an $(x + y)$ pole motor. This is simply the ordinary "Cascade" system, and in the numerical example given by Mr. Field the speed of the combination would be 12·5 revs. Mr. Hunt.

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Mr. Hunt. per second. For a speed of 25 revs. per second the relative directions of rotation of the two fields would have to be reversed.

The next point mentioned by Mr. Field has reference to the use of a one-speed "Cascade" motor, and he referred to the disadvantages of the "Cascade" system as mentioned in the paper. The paper was intended to describe the means by which these difficulties had been overcome. The machine as now developed is as efficient as a slip-ring motor, and is cheaper to build. Control of the starting torque and speed is similar to that of a slip-ring motor, with the important difference that in one case the resistances are connected to the rotor windings through slip-rings, and in the other case to the stator windings. I think it is generally agreed that slip-rings require almost as much attention as commutators, and mining engineers are particularly desirous of doing away with slip-rings wherever possible. The starting efficiency of the machine under discussion is really better than that of a slip-ring motor, because by suitably arranging the x and y pole rotor windings it is found that the starting torque is constant for any position of the rotor. A considerable variation is found in a slip-ring motor.

The rotor of a one-speed motor has a short-circuiting ring at each end connected to alternate bars, the remaining bars are riveted or bolted to cross connections. The construction is therefore exceedingly simple and quite as mechanical as that of a squirrel-cage rotor. Where, for such work as hauling or winding, it is necessary to control the speed of a slip-ring motor, the brush contact and friction losses are very appreciable, as it is not possible to short-circuit the rings or lift the brushes. These losses are, of course, absent in the new motor.

Mr. Field next referred to the multi-speed motors and to sacrifices which have to be made if an induction motor is required to run at more than one speed. I am in agreement with him if his remarks be taken to apply to two separate "Cascade"-connected machines. Tests have proved that the objections have been overcome in the motor described in this paper. I will briefly indicate the essential differences between the new motor and two separate "Cascade"-connected machines. The latter arrangement as regards the C^2R losses is equivalent to a single motor having a double-wound stator. Reference to the table printed in the paper will show that with such windings the stator losses are about 2·1 times as great as in the tapped single winding. Where two separate motors are used the amount of iron required in the cores is a function of the sum of the two magnetic fields. In the new machine it is only necessary to make the iron sufficient to take the flux of the field having the smaller number of poles. I have worked out some approximate figures for a two-speed 200-B.H.P. motor, wound for 8 and 4 poles. The full speed when run on a 40-cycle circuit would be 590 r.p.m., and the second speed 394 r.p.m. At full speed and load the efficiency would be 93 per cent. At the lower speed the motor would give 150 B.H.P. with the same temperature rise, and its efficiency

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Mr. Hunt.

would be 91 per cent. The motor would develop a starting torque equal to twice full load torque taking only 1·4 times full load current. With full load current it would develop about 1·45 times full load torque. Comparing this machine with an ordinary slip-ring motor, the same frame and stampings would be used, but there would be more iron in the teeth of the "Cascade" machine than in those of the slip-ring motor. The core would be slightly longer, but the weight of copper would be about 150 lbs. less. The cost of the two-speed motor would be less than that of the one-speed ordinary type machine.

As to the use of a mechanical device for changing speeds, I think that such an arrangement would be very suitable for small motors, but for machines of large size there would be very grave objections. I do not think that mining engineers would permit of their use. A few years ago I devoted some time to an attempt to develop a form of epicyclic gearing for use with motors of moderate size, but was everywhere met with the objection that what was wanted was a reduction and not an increase in the amount of gearing. The present tendency to couple motors direct to winding engines, pumps, etc., without the use of any gearing is evidence of the growth of this feeling.

Mr. Field's illustration bearing on the interlinking of a winding of one number of poles is very interesting. The rule given in the paper ensures non-interlinking of the windings, but this is not the only point to be considered in determining a suitable number of poles, because it is possible to choose numbers which will comply with this rule but will give an unsymmetrical resultant field. The 6- and 4-pole combination mentioned by Mr. Field would produce an unsymmetrical resultant field. His diagrams in Fig. B show 4-pole and 2-pole magnetic fields.

There would be no interlinking with these pole numbers, but if the two diagrams be superimposed it will be seen that the N poles will coincide at one point of the rotor, whilst diametrically opposite there will be N and S poles. The result would be a greatly increased magnetic pull at one point and a much weakened pull at the other. This unbalanced force is sufficient to cause the rotor to revolve eccentrically, and consequently this number of poles would prove unsatisfactory, for even with a sufficiently strong shaft the wear on the bearings would be excessive. Of course, by using two rotors on the same shaft and suitably staggering them this difficulty might be overcome, but the arrangement would be expensive except for large high-speed machines such as are required for driving centrifugal pumps.

In order that the resultant field shall be symmetrical, it is necessary that the G.C.M. of the two numbers of poles shall be an even number greater than 2.

Mr. Wilson asked for further explanations of the diagrams. With regard to the stator windings, they are of the ordinary type and similar to those used on standard machines. The only difference is that they

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Mr. Hunt. are grouped in parallel circuits and provided with tappings. Fig. 11 shows a rotor having two windings, the outer circles representing the mesh-connected 4-pole bars, and the inner the star-connected 2-pole bars. The windings are of ordinary type, connected as shown. Figs. 12 and 13 show a 6-phase winding suitable for one-speed motors where the resultant number of poles is equal to $(x+y)$. The magnetic fields rotate in opposite directions.

Fig. 14 shows a simple 4-pole winding, and Fig. 15 a similar 2-pole winding. If these be placed upon the same rotor core it will be seen that in some slots the two currents will always be flowing in opposite directions, and in others in the same direction. It is clear that if two bars carrying equal currents which flow in opposite directions are placed in the same slot, they can produce no useful magnetomotive force, and consequently they may both be omitted. Removing the useless conductors in this manner gives the winding as shown in Fig. 16. Fig. 19 is another resultant winding, and is derived from the windings shown in Figs. 17 and 18 by taking out conductors which cancel one another. A word of explanation is necessary as to the windings shown in Figs. 17 and 18. It will be seen that in Fig. 17 the centre set of conductors have been moved relatively to the inner circle of bars through an angle (electrical) of 60°. The difference in phase between the two currents in any one slot is consequently 60°, and the resultant ampere-conductors per slot equals 1·73 times the current in one bar. In Fig. 18 the outer circle of conductors has been rotated relatively to the inner circle of bars through an angle (electrical) of 120°, and consequently the resultant ampere-conductors per slot equals the current in one bar only.

Mr. Wilson has mentioned the question of using regulating resistances for speed control. In a one-speed motor any speed below synchronism can be obtained by inserting resistances between the tappings of the stator windings. In the same way, with a two- or three-speed motor, any speed between the efficient speeds can be obtained by the use of resistances; in fact, the control of a two-speed motor is very similar to that of a double-commutator continuous-current machine, as mentioned by Mr. Wilson. In replying to Mr. Field, I have touched upon the question of cost, but I may add that the values of D^2L of these machines are approximately the same as those of slip-ring motors of the same output and speed. The slots are, however, shallower, and less copper is used.

I regret that I have not been able to give any definite test figures, but I preferred to defer doing so until the completion of further tests. Several motors have been built and tested, but the designs were not good, as the iron density was far too high and the copper density too low. However, before the paper was written, sufficient data were obtained to prove clearly that machines having excellent electrical qualities could be built, and standard designs have now been prepared. Of the tests already made, mention may be made of the following: A small 12-pole 14-in. motor was found to have a power factor of 0·81,

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which, I think, is high for a machine having so small a pole-pitch. The length of the air-gap was larger than necessary, and with a smaller gap and properly proportioned iron and copper a better result would have been obtained. A small 10-in. motor had a power factor of 0·83. The rotor winding was of the concentrated type with deep slots. The value would have been 0·85 with a more distributed form of winding. The output was 12 B.H.P. and the overload capacity 100 per cent. Mr. Hunt.

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FURTHER NOTES ON ELECTRICAL CONDUCTIVITY; STATIONARY CONTACTS, OILED AND DRY.

By WILLIAM BROWNING, Wh. Ex., Student.

(Paper read before the Manchester Branch of the Students' Section, February 15, 1907.)

This paper is a continuation of the subject dealt with in my paper * of last session, and contains the results of further research which I have carried out in the Electrical Laboratories of the School of Technology on the conductivity of contacts, with special reference to contacts in oil.

The objects of the research were :—

1. To examine the factors which determine the critical pressure of a contact in oil, that is, the pressure at which the conductivity assumes a constant value, the conditions of temperature and current density being constant.
2. The relation between current density and conductivity.
3. The relation between temperature and conductivity.
4. To compare the above with the results obtained with a dry contact.

Apparatus and Materials Used.—The apparatus differed a little from that previously used, but the method was the same, namely, the resistance was obtained by measuring the drop in potential across the contact for a known current. A galvanometer, giving 1 cm. deflection for a difference of potential of 0·01 millivolt, was used for obtaining that resistance. The contact pieces were of soft copper of 1 sq. in. area. The previous contacts were of brass of 1·54 sq. in. area. The softness of the copper seems to have had an influence on the results, which will be pointed out when these are considered.

The area of contact given is that indicated by the dimensions. No good method could be arranged by which to ascertain the absolute area of the contact, so the results were calculated on an assumption of 100 per cent. efficiency of contact. Thus the conductivity, as calculated, will be low, and, in the case of two contacts of different area, the smaller will appear to have the greater conductivity, because a smaller area will generally have the higher efficiency of contact.

* *Journal of the Institution of Electrical Engineers*, vol. 37, p. 372.

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The mechanical pressure was applied by a lever system, in such a manner that it could be varied without causing any disturbance of the contact. The arrangement was a lever of the second order, with a ratio of 1 : 3, and the pressure was transmitted to the contacts through a hemispherically rounded metal stud which ensured uniformity of the point of application and direction of the pressure. This was found to be superior to the method previously adopted, which was the direct application of weights to the contacts, when it was found, with the smaller sizes of contact, that uncertain results were often obtained, due to the accidental shifting of the weights.

In the first section of the work different oils and other media were used, in which to immerse the contacts, but in the second and third parts only one oil was used, a resin oil of which an analysis and test gave the following particulars—the nature and quality, a pure resin oil, free from all fatty and mineral oils :—

Specific gravity at 70° F. ...	0·975
Viscosity at 36° F.	616
Viscosity at 70° F.	76·8

(The standard being the viscosity of rape oil at 60° F. = 100.)

Crucible flash point	310° F.

Dielectric strength, an alternating voltage of 4,000, broke down a gap of 0·056 ins. between two hemispherically ended brass rods, ½ in. diameter.

Method of Working with the Oil.—For some of the experiments the oil was placed in a containing vessel, in order to imitate the natural conditions of an oil switch. This, however, provided an experimental difficulty, and an investigation was made of the difference between "a contact in oil" and "an oiled contact," when it was established that they were electrically one and the same. An oiled contact is one in which the contact pieces have been flooded with oil before being placed in contact. This method was adopted in the second and third sections of the research, hence the title of the paper contains the term "oiled contacts."

Temperature of the Contacts.—When the oil bath was used, a thermometer in the bath gave the temperature, but when no bath was used the temperature was ascertained by means of two thermo-couples of Eureka and copper wires, employing the "null" method. One junction was wrapped in a wisp of cotton wool and placed in the oil which was flooding the metal of the contact pieces, thus making a good thermo connection with the contacts. The second junction was immersed in an oil bath, the temperature of which could be varied at will. The two were then placed back to back in series with a galvanometer. Then, if the junctions were similar, there would be no deflection shown by the galvanometer at equal temperatures of oil bath and contact. When the contacts were dry, the junction was attached to the metal by a piece of soft putty, which method gave good results. Before using, the arrangement was calibrated by heating the two

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junctions to equal temperatures and noting if any deflection showed lack of similarity.

Precautions for Oiled Contacts.—There were three probable effects which might have affected the potential difference across the contacts due to the passing of a current. They may be named: A voltaic effect, a thermo-electric effect, and an electrolytic effect.

The voltaic effect, a difference in potential caused by a dissimilarity in the metal of the contact surfaces, which may be increased by the presence of the oil. This difference in potential would always be present, and would be independent of the current. The voltaic difference of potential was found at a temperature of 16° C. to fall between the limits of 0·0002 and 0·0001 millivolt and to have a polarity which increased the difference of potential due to the passing of the current.

The thermo-electric effect, a difference of potential, also caused by a dissimilarity of the metals, and, like the previous effect, independent of the current. When the contact temperature was raised the thermo effect would become evident, but also with it the voltaic effect may alter, hence the two cannot be separated. The combined potential difference at a temperature of 44° C. had a value which fell between the limits of 0·0002 and 0·0003 millivolt, with the same polarity as before.

The third effect is one which would be present if the oil were in any degree electrolytic in its action, and would be due to polarisation. Its polarity would be dependent upon the direction of the current, and, generally, would have the effect of increasing the difference of potential due to the current. This effect was not present, as no difference was found in the potential difference of the contacts before and immediately after a current had been flowing.

These differences of potential are so very small compared with the differences due to the current, except at the low values of the current density of Fig. 3, where they have had the tendency to reduce the steepness of the curve, but where, however, they only fall within the probable error of the reading, that the readings have not been corrected for these effects.

In the course of the work it was noted that under certain conditions there was a lag of the conditions of the contact, as indicated by its conductivity, behind the changed external conditions, that is, a time element entered into the results. This was particularly noticeable in the case of the pressure-conductivity curves for increasing and decreasing mechanical pressure. Curves I. and II. in Fig. 1 are such. An interval of about three minutes occurred between the change in the conditions of pressure and the reading of the potential difference. The conditions of the experiment were: Material of the contacts, soft copper; area of the contact, 1 sq. in. at 100 per cent. efficiency; oil, resin oil, not contained in a bath; current density, 50 amps. per sq. in.; temperature, about 40° C. The time element is only present during the lower part of the curves. Above the pressure of 13·5 lbs.

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per sq. in. there seems to be no lagging in the condition of the contact.

Considering the loop portion of the curves, it became evident that if the film of oil was thinned by an increase in the mechanical pressure, and so was made to flow out from between the contacts, the viscosity of the oil would oppose the thinning-out process and cause a time lag; also, when the pressure is being reduced, and that force which opposes the pressure and prevents actual contact between the metal, tends to increase the thickness of the film, the viscosity would act to oppose the change. That is, it now acts in the opposite direction, and an area is enclosed between the curves.

The curves of resistance, III. and IV., Fig. 1, were obtained by calculation from I. and II., when it was found that the area enclosed

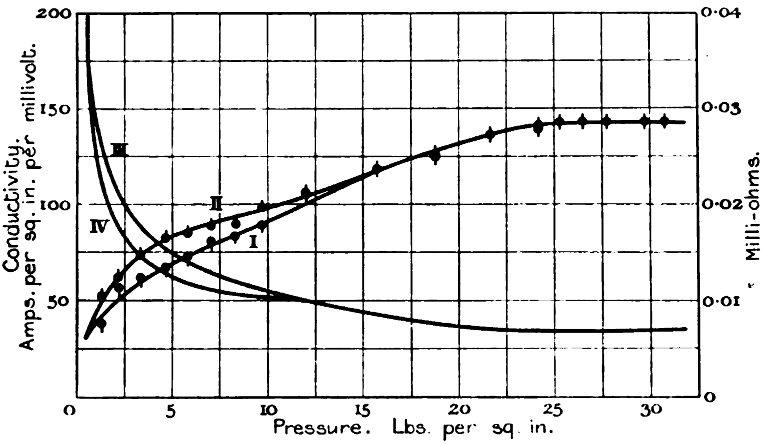

FIG. 1.

by the resistance curves could be made to form the basis of an interesting investigation:—

The area is a product of resistance and lbs. weight which, when expressed in their fundamental units, indicates that the area represents a rate of work which will be the rate of doing work against the viscosity as the oil is caused to flow from between the contacts. This multiplied by the time of one operation, for instance, the time of squeezing out the oil, will give the total work done in that half of the cycle.

This work is also equal to the product of the difference between the applied pressure and the force of the film which opposes this pressure, and the distance through which the contacts move. By equating these two expressions, the amount of thinning of the film can be found. This will give, when multiplied by the area, the volume of the oil squeezed out; hence, with the final thickness of the film as the unknown, an expression may be obtained for the work done against

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the viscosity as it flows out from between the approaching contacts. Equating this to the first expression for the work done, the final thickness of the oil may be obtained.

The consideration of these curves seems to indicate that they are made up of two parts in which the cause of the change in the conductivity by a change in the mechanical pressure is different. In the lower part of the curve the loop indicates a flow of the oil, and the conductivity is increased by a thinning of the film. The length of this part of the curve will depend upon the rate of increase of the pressure, the greater the rate the longer will be this part of the curve.

In the upper part different conditions seem to exist. An increase in the pressure does not seem to cause the oil to flow, or if it does the oil must be in such a condition that the force of viscosity has no further retarding action on the flow.

A film of oil between two glass surfaces, under pressure, shows the dark spaces and the coloured bands as are seen in Newton's ring experiments with light, indicating that the film is in parts approaching the limit of thinness. At this point the oil may break up into small patches, as can be seen when an oil of less surface tension than water is allowed to spread over a large surface of water.

After the critical pressure is passed the film is in some condition unaffected by pressure, and at the actual points of contact may be only a few molecules thick.

During current density and temperature-conductivity determinations, when the contacts were under pressure for a period of about four weeks, a different time effect was observed. It was a gradual increase in the conductivity, under similar conditions, with time. This was ascribed to a gradual increase in the efficiency of the soft copper contact due to the gradual flattening out of the bearing points under the constantly applied pressure.

These various points which have been fully expanded are very important for the correct interpretation of the results.

Factors which Determine the Critical Pressure of a Contact in Oil.—It was stated in my previous paper that probably the viscosity was one of the factors which determined the critical pressure; but the viscosity of the oil is only evident as a force when the oil is in motion, and then is dependent upon the rate of flow. Now the value of the critical pressure is independent of the rate of increase of the pressure, provided the rate is not so great that the loop portion is made to extend over the whole of the curve, and the oil of the film at the critical pressure is stationary. Hence the above statement is not correct for the conditions which existed during the experiments.

The effect of employing media having different surface tensions was investigated, with the result that a close connection was found to exist between the surface tension and the critical pressure. The exact relation was not, however, established. It was found that, with the media examined, the greater the surface tensions the greater is the critical pressure. Pressure-conductivity curves were obtained under

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similar conditions for a variety of media. The results of four are given in Fig. 2 and are for the following cases :—

I. Olive oil; II. a mixture of equal volumes, before mixing, of alcohol and tap water; III. resin oil; IV. tap water.

The conditions were: Material of contacts, an electrolytic deposit of copper on brass; area of contacts, 1·54 sq. in. The current density, 50 amps. per sq. in.; temperature, 30° C.; the liquids were contained in a bath.

The critical pressures are, in the order of the curves: 21·5, 20·5, 26, and 24 lbs. per sq. in.

The surface tensions were not actually measured, but were compared by the following experimental data: An oil having a less surface tension than water will, when dropped on a free surface of water,

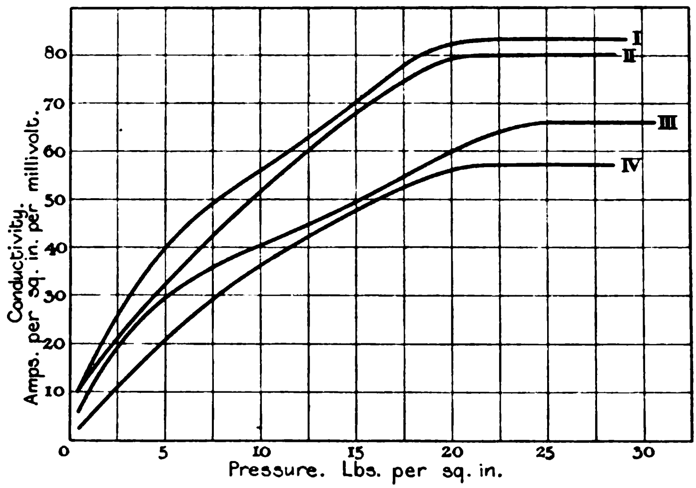

FIG. 2.

immediately spread out as far as possible until the whole surface is covered or the thinness of the film reaches the limit. If the surface tension is greater than that of water the above will not take place. Tested in this manner, olive oil has a less surface tension than water, and the critical pressure of the contact is less with it than with water; resin oil has a slightly greater surface tension than water, and the critical pressure of the contact is slightly greater with it than with water. Again, it can be demonstrated that the addition of alcohol to water reduces the surface tension, and the addition has also reduced the critical pressure of the contact.

A comparison of the values of the critical pressures obtained at equal temperatures with different-sized contacts showed that they were independent of the area of contact, hence we may infer that the value

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of the critical pressure only depends upon the surface tension of the medium in which contact is made.

Relation between Current Density and Conductivity.—The conductivity was found to vary with the current density. The conductivity is therefore a function of two variables—the mechanical pressure and the current density—and the complete relations may be determined by ascertaining the relation between any two for different values of the third. The method adopted was to obtain current-conductivity curves for different mechanical pressures. Fig. 3 contains the resulting curves. Curve I. shows the relation at a pressure of 6·25 lbs. per

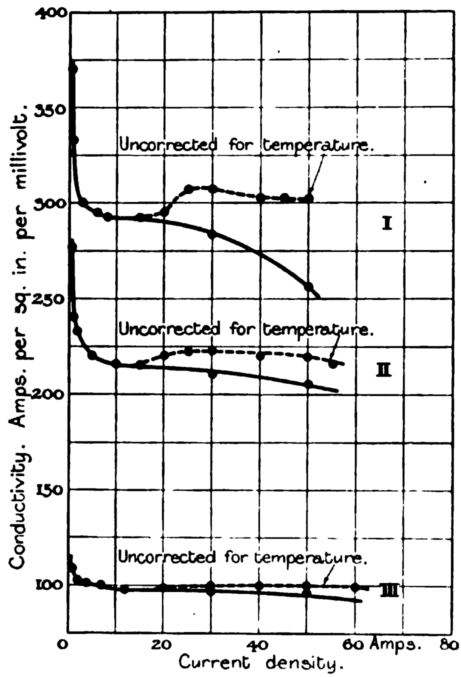

FIG. 3.

sq. in., II. at 18·25 lbs. per sq. in., and III. at 30·25 lbs. per sq. in. These results have been corrected for temperature variation, being corrected to 17° C.

The method of conducting the experiment was: Readings were taken of potential difference across the contacts and temperature, for a certain constant pressure with varying current densities. The contacts were then allowed to cool and to regain their former conductivity. They were then heated gradually, by passing a current through them, and, as the temperature increased, readings of temperature and potential difference across the contacts were measured

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for different current densities. The whole series was then repeated for a different value of the pressure.

What may be the physical explanation of the results in Fig. 3, I am not, at present, in a position to explain, but an examination of the results, however, has revealed some points which are worthy of note: the variation of conductivity with current density increases with the pressure; it is least where the oil film is thickest, and increases until it is greatest where the film is in its limiting condition for the temperature to which the curves are corrected; also at the higher readings of the current densities there is a convergence of the curves which seems to indicate that there may be a value of the current density where there is no, or very little, pressure-conductivity variation.

Relation between the Conductivity and Temperature.—The conductivity was found to increase with temperature. The first object of the temperature curves was to correct the current-conductivity curves for

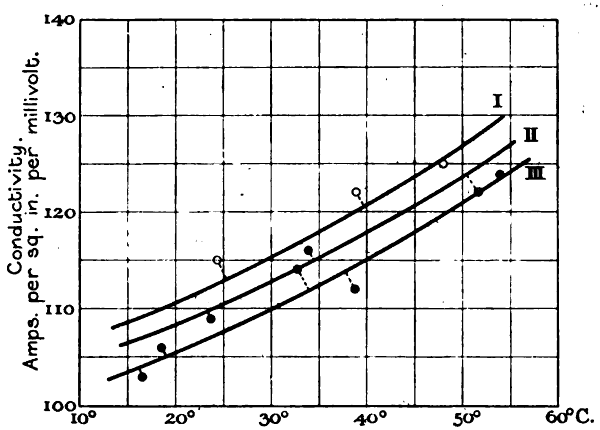

Fig. 4.

temperature variation, hence they were obtained for increasing temperatures that the conditions might be the same in each case. Besides the time variation in the conductivity which has already been mentioned, there was noticed, in the case of the lowest pressure more particularly, a lag similar to that observed in the variation of mechanical pressure, the curve of decreasing temperature and conductivity took up a higher position, but when allowed to cool completely the difference decreased and the conductivity became constant at a value slightly greater than its former value. The cause of which was discussed under the heading of "Precautions."

The conductivity is now made to depend upon three variables, hence the relation between the conductivity and temperature was determined, as described above, for various values of current density at different values of the mechanical pressure. The results are given

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in the curve of Figs. 4, 5, 6. In Fig. 4 the pressure was 6·25 lbs. per sq. in., and Curve I. indicates the relation between temperature and conductivity at a current density of 10 amps. per sq. in., Curve II. at 30 amps. per sq. in., Curve III. at 50 amps. per sq. in.

In Fig. 5 the pressure was 18·25 lbs. per sq. in., and Curve I. the relation at 10 amps. per sq. in., Curve II. the relation at 30 amps. per sq. in., and Curve III. the relation at 50 amps. per sq. in. In Fig. 6 the pressure was 30·25 lbs. per sq. in., and Curve I. the relation at 10 amps. per sq. in, Curve II. the relation at 30 amps. per sq in., and Curve III. the relation at 50 amps. per sq. in.

Comparing the results, it is found that they indicate series of interesting relationships; for instance, between the rate of change of conductivity with temperature and the mechanical pressure. The average rate of change, say, from 20° C. to 45° C., increased with the pressure, and the actual rate of increase, in the two lower pressures, first increased with the temperature and then tended to become constant, while at the highest pressure it commenced almost uniform, and as the temperature increased it decreased at a rate which increased with the temperature. Thus the curves in Figs. 4 and 5 are concave to the axis of y, and the curves in Fig. 6 are concave to the axis of x. A further series is the relation between the rate of change of conductivity with current density and the temperature at the different pressures. At the pressure of 6·25 lbs. per sq. in. in Fig. 4 the rate of change of conductivity with current density increased slightly with an increase in temperature; at the pressure of 18·25 lbs. per sq. in. the rate of change slightly decreased with a temperature rise, and at the pressure of 30·25 lbs. the rate of change had a marked decrease with an increased temperature. Thus the cases of Figs. 4 and 5 are alike in one respect, while the cases of Figs. 5 and 6 are alike in another. Reference to the pressure-conductivity curve of Fig. 1 shows that the case of the pressure 18·25 lbs. per sq. in. is similar to that of the 6·25 lbs. per sq. in. in one respect, and to the 30·25 lbs. per sq. in. in another, for the cases of the pressure 6·25 and 18·25 lbs. are similar in that a change in pressure produces a change in the conductivity, and the pressure of 18·25 and 30·25 lbs., in that the film is in such a condition that an increase in pressure does not seem to cause any oil to be expelled from between the contacts, from which it seems probable that the conditions which cause the one also cause the other.

It was established in the first section of the work that the value of the critical pressure was determined by the surface tension, and therefore it will be a great factor in determining the values of the conductivities below the critical pressure. For if by some means which does not alter any other determining characteristic the surface tension be reduced, then the curve of conductivity and pressure will be displaced to the left and the values of the conductivity for all pressures below the critical pressures will be increased; above the critical pressure the value will not be changed.

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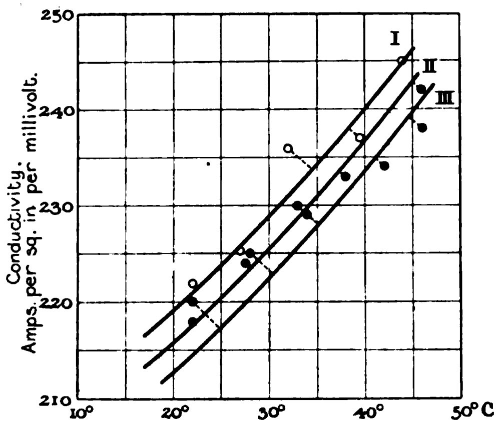

FIG. 5.

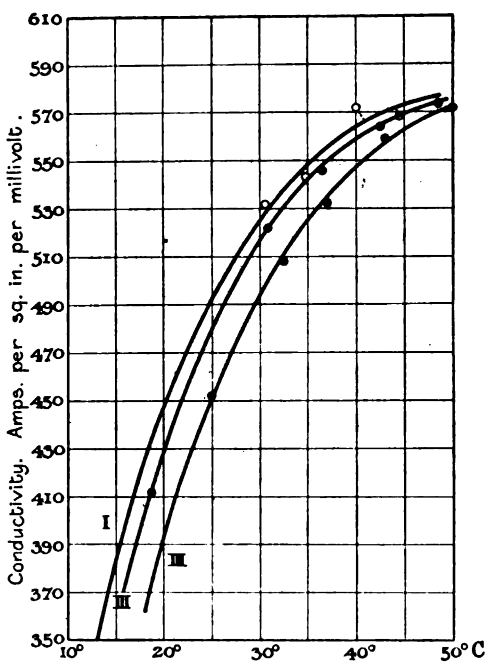

FIG. 6.

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One of the effects of an increase of temperature is a decrease in the surface tension which for liquids in general follows the law

$$a_t^2 = a_o^2 (1 - a\,t + \beta\,t^2)$$

where "a_o" is the surface tension at 0° C., and "a_t" the surface tension as t^o C., and a and β are constants, "β" being small compared with a. This gives a curve concave to both axes which falls to zero at the boiling-point, therefore the change in the critical pressure and the corresponding change in the values of the conductivity for pressures below the critical pressure may be expected to follow a curve which is concave to the axis of y. This would apply to the cases of the pressures of 6·25 and 18·25 lbs. per sq. in.

In the case of pressures above the critical pressure the increase in conductivity with temperature must be due to a different cause. The molecule, which is very complex, will, when the temperature is increased, undergo changes in its arrangement which will greatly affect the conductivity when the film is very thin. However, I have not been able to obtain a definite statement of what the changes probably are or how they would affect the conductivity.

Comparison of the Characteristics of a Dry Contact with those of an Oiled Contact.—The dry contact was found to be even more variable than that in oil. The oxidation at ordinary temperatures was found to have a marked effect upon the conductivity when the contacts were allowed to stand.

The contacts which had been used for the oil experiments were cleaned in boiling caustic, to remove the oil, and then freed from oxide by boiling potassium cyanide. They were placed in contact with a mechanical pressure of 30·25 lbs. per square inch, and the current-conductivity relation obtained. The curve showed very peculiar characteristics. For an increase in the current density from 0·5 to 3 amps. per sq. in., the conductivity increased some 200 per cent., when its rate of change suddenly decreased, and it continued to rise slowly as far as the readings were taken. The temperature-conductivity curves were then obtained to correct for temperatures. These were found to have a rate of increase which increased rapidly with the temperature and to indicate that the rate of change of conductivity with current increased rapidly with temperature. When the current-conductivity curve was corrected for temperature it indicated that after a current density of 5 amps. per square inch was reached the conductivity slowly decreased in value. These curves have not been given for the reason that, as the cooling temperature conductivity was taken, the conductivity did not return along a similar curve but remained almost constant, which showed that a non-reversible change had taken place. When the current was first passed, it seemed that air was expelled, at first quickly, and afterwards slowly, the quick period extending over about ten minutes; when this was passed the reduction of the conductivity, due to the oxidation of the surfaces in contact, became evident. During the process of heating up, the expelling of the air

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masked the oxidation effect and the conductivity increased permanently. At this stage the contacts were cooled and a current-conductivity curve was obtained, which is Curve I. in Fig. 7; then they stood for a day, when Curve II. was obtained, showing the decrease in the conductivity due to the natural oxidation of the contact metals at the ordinary temperature. They were then heated and the conductivity was found to decrease with time at constant temperature; after a period of two hours' heating at a temperature of 50° C. they were allowed to cool when the Curve III. was obtained. There was no temperature-conductivity variation.

These results seemed to show a great difference in the behaviour of an oiled and a dry contact, which must be due to the action of the oil. The comparison of the values of the conductivity of the oiled with those of the dry contact requires a word of explanation; the contacts

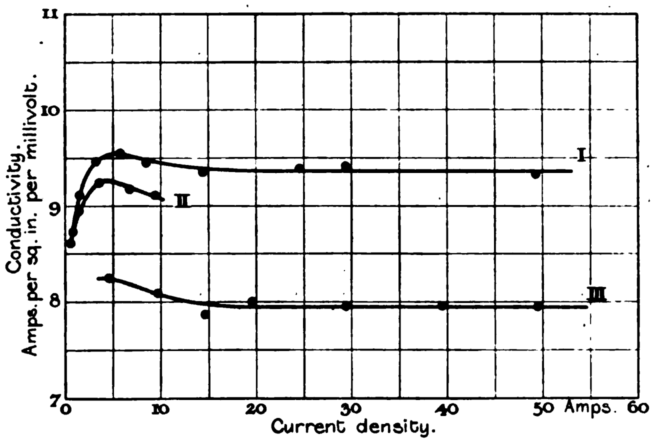

FIG. 7.

were not used for the dry contact determinations immediately after the oiled contact experiments were completed, but were laid aside for a time and so may have had, as the results lead me to think, their efficiency reduced. So it would not be right to compare the value as given above to obtain the comparison. Some determinations were made, however, with that object on the 1 sq. in. soft copper contacts, and also on a laminated switch contact.

The conditions and particulars for the former case were:—

Pressure, 30·25 lbs. per sq. in.
Current, 10 amps. per sq. in.
Temperature, 18° C.
Conductivity, when dry, 26·8 amps. per sq. in. per millivolt.
" when oiled, 96·0 " " "

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The conditions and particulars of the latter case were :—

Area of contact, assuming 100 per cent. efficiency, 1 sq. in., made up of eight laminations, 1·25 in. × 0·05 in, average inclination, 30°.
Pressure of contact was not determined.
Current, 50 amps per sq. in.
Temperature, 18° C.
Conductivity, when dry, 90 amps. per sq. in. per millivolt.
„ when in oil, 128 amps. „ „

It will be seen on reference to the curves of Fig. 8 that the conductivity curves for the laminated switch contact follow laws similar to those for the plate contacts.

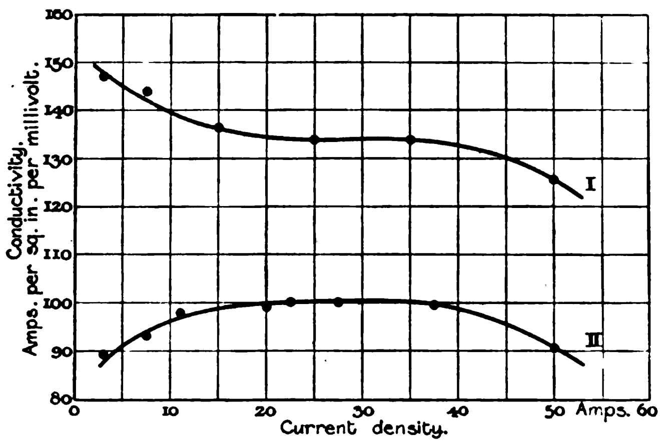

FIG. 8.

In the case of the dry contact, Curve II., the conductivity decreased at the higher current densities; from this it was inferred that the surfaces of the contact, which as the switch was closed would undergo a cleansing action, were becoming oxidised by the air which was trapped between the surfaces. There was a rise of 2° C. in the temperature of the contact when 50 amps. per square inch was reached.

The results show the superiority, from the point of view of conductivity, of an oiled contact over a dry one, especially at low-current densities, and further, that the conductivity of the dry contact is decreased by oxidation which takes place on the surfaces of the metals when in contact. In a paper by Dr. P. E. Shaw *, which, in its conclusions, supports the results obtained in this paper, a good experimental proof of the difference of the conductivity and behaviour of dry

* "Disruptive Voltages of Thin Liquid Films between Iridio-platinum Electrodes," *Phil. Mag.*, vol. xii. p. 317.

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and oiled contacts is given. In the description of the experimental work it describes how the contact between two iridio-platinum electrodes was determined by placing them in a telephone circuit, and how, when they were in oil, the sound given out by the telephone was very clear and distinct as compared with the sound when the contacts were dry.

In conclusion, I desire to thank Mr. Garner for his assistance in the practical work, Professor A. Schwartz for his advice, Mr. L. G. Radcliffe for his assistance in the analysis of the oil, and the Principal and Committee of the School of Technology for permitting me to carry out the research in the laboratories of the school.

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ELECTRIC "VALVES."

By E. W. MOSS, Student.

(Abstract of Paper read before the Students' Section, London, Wednesday, May 1, 1907.)

THE ELECTROLYTIC RECTIFIER OR NODON "VALVE."

Theory.—"Valve effect" is a general one obtained by means of any metal dipped in an electrolyte and the whole subjected to a definite difference of potential. Metals of low atomic weight, as magnesium and aluminium, produce the effect under high difference of potential, while heavy metals, as mercury and lead, produce it under a low difference of potential.

In theory the nature of the anode is without influence on the valve effect, if the relative surface is sufficient, but in practice lead or iron is generally used. The nature of the metal used as cathode plays an important part in the phenomenon, and an aluminium alloy is generally used. With aluminium as a cathode M. Nodon found that the best results were obtained with a solution of neutral ammonium phosphate; he came to the following conclusions*:—

1. Aluminium gives rise to the phenomenon of valve effect to a much greater degree than any other metal.
2. Cathodes are attacked when potassium and sodium salts are used, imperfect valve action results, and a precipitate of alumina is produced with aluminium electrodes.
3. Only carbonate, oxalate, or phosphate of ammonium produce the desired result; the addition of another salt reduces the valve effect, and of the above the neutral phosphate of ammonia gives the best results.
4. Increase of internal resistance of the valve is demonstrated on opening the circuit and at the instant of reversal of the current.
5. The valve effect is complete up to about 30° C., and after this the leakage increases up to boiling-point.

From the above results M. Nodon concludes that the best practical arrangement for an electric valve consists of—

1. A cathode of aluminium alloyed with a small proportion of a foreign metal.

* *Electrician*, Vol. 53, p. 1037, 1904.

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2. An anode of lead of larger surface than the cathode.
3. An electrolyte of a concentrated solution of neutral ammonium phosphate.

The action of the electrolytic "valve" appears to be that a film * of normal hydroxide of aluminium ($Al_2(HO)_6$) forms over the aluminium plate, which, when the aluminium is the anode and the potential below a certain value, will not allow current to pass from the aluminium to the lead in the cell, but when the aluminium is the cathode allows current to flow from the lead to aluminium, *i.e.*, the film becomes of low resistance in this direction. S. R. Cook † says there are two potentials depending on the temperature at which the film undergoes a change, so that the resistance to the passage of ions is decreased, the first being about one-third the second. The second potential is the critical value, *i.e.*, the point at which the resistance of the film breaks down, due to crystallisation. If an increasing voltage is impressed on the cell when it reaches a value a little below the critical value, the phenomenon of

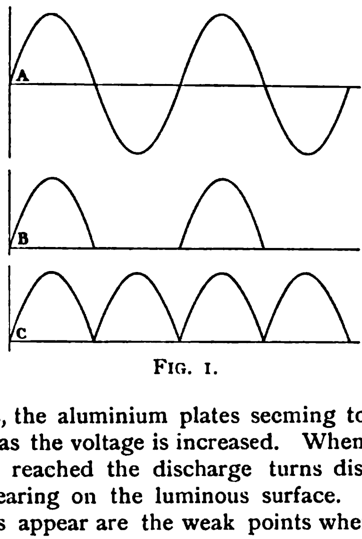

FIG. 1.

luminosity occurs, the aluminium plates seeming to glow with a faint phosphorescence as the voltage is increased. When the critical value of the voltage is reached the discharge turns disruptive, stars and scintillations appearing on the luminous surface. The places where these scintillations appear are the weak points where the film breaks down, but the phenomenon remains continuous, as the film is renewed by the action of the current where broken down.

Description of the Nodon "Valve."—The Nodon "Valve" is constructed by Mors & Co., of Paris, and Snowdon & Co., of London. It consists of a cylindrical containing vessel of iron, in which is placed a cylindrical plate of lead, which acts as the anode. In the centre of the vessel is placed the cathode, which consists of a hollow rod of an aluminium alloy. It is only a small portion at the bottom of the rod which is utilised for "valve" effect, and this is made of larger diameter

* K. Norden, *Electrical World*, vol. 38, p. 681, 1901.
† *Physical Review*, vol. 20, p. 312, 1905.

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than the rest of the rod, the current density being 5 to 10a per square decimetre. The part of the rod not used for "valve" effect is covered by a glass tube and only acts as a path for the current, the whole rod being insulated from the bottom of the containing vessel and being kept in an upright position by passing through the insulating covering of the top of the containing vessel. The cell is filled with the electrolyte to the top. When working, water is passed through the hollow aluminium rod in order to keep the apparatus cool. In the larger sizes the water cooling is not sufficient, and then the cases are made double, so that cooling is effected by blowing a stream of air through by means of a fan driven with a small current taken through the cell.

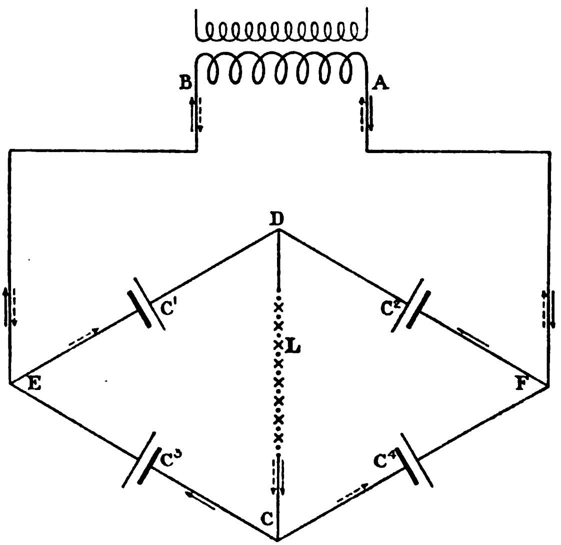

FIG. 2.

Arrangement of Cells.—If one cell only is used across the mains of an alternating-current circuit, since the cell passes current in one direction only, a pulsating unidirectional current will flow through it. This current will vary over one-half of a sine curve when the impressed E.M.F. is such as to cause a current to flow through the cell, but while the impressed E.M.F. tends to cause a current to flow in the opposite direction, no current will flow through it, *i.e.*, only one-half of the alternating supply wave is used, as is shown in Fig. 1. Curve A is the supply E.M.F. curve, and curve B is the curve of the current which flows through the cell, it being a current which varies between 0 and a maximum for one-half period and is 0 during the next half period. By using the grouping invented by Grätz, both halves of the supply wave may be used and a pulsating unidirectional current may be

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obtained which has only an instantaneous zero value, as is shown in curve C, Fig. 1.

The Grätz method of arrangement consists in the employment of four cells arranged so that there are two paths for the current and through each path the current can flow in only one direction. In Fig. 2 is shown the arrangement, which is also very often called the Wheatstone Bridge arrangement. C_1, C_2, C_3, and C_4 represent the cells, the long thin line being the aluminium plate and the shorter thick line the lead plate. The load is marked L, and is connected across the junction D of two aluminium plates and the junction C of two lead plates. The two junctions E and F of a lead of one cell and an aluminium of another cell are connected to the supply circuit. The Nodon "Valve"

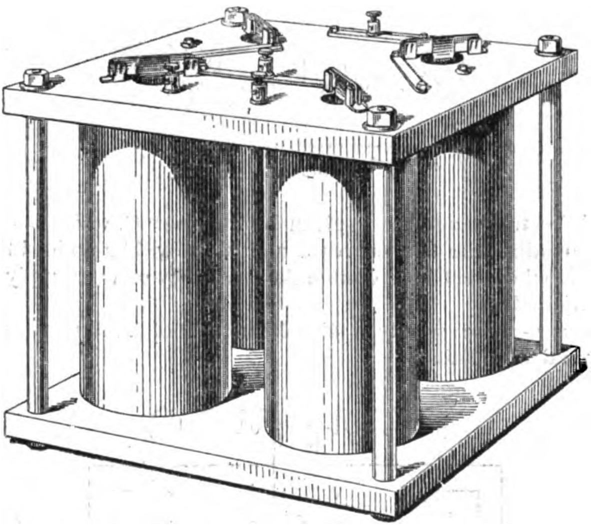

FIG. 3.

is supplied in this form, *i.e.*, four separate cells fastened together between two slabs of slate and electrically connected in the Grätz method (Fig. 3).

Mode of Operation of the Valve.—Referring to Fig. 2, imagine the current to be flowing in the transformer A, B, from B to A, then it enters the valve at F and the full-line arrows (⟶) show its course. Since the current can only flow from the lead to the aluminium, it is unable to pass through cell C_4, and therefore it passes through cell C_2, then through the load L, through the cell C_3, and out at E to the transformer at B. When the direction of flow in the supply is reversed the current enters the valve at E, passes through cell C_1, load L, cell C_4, and out at F to the transformer at A, as shown by the dotted arrows (⟶). It is thus seen that, whatever the direction of the current in the supply, the direction of the current flowing through the load is always the

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same, and its value varies between o and a maximum with twice the periodicity of the supply, as is shown in curve C, Fig. 1.

The cells may be used on circuits of more than one phase. Fig. 4 shows the rectification of a 2-phase current. A and B are the two current waves in quadrature with each other, and these are rectified to the two currents *a* and *b* which flow through the load. Therefore the

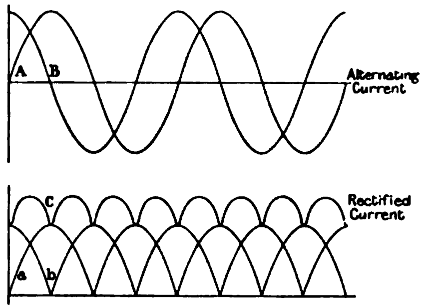

FIG. 4.

total unidirectional current is given by the curve C, which is obtained by compounding the two curves *a* and *b*. It will be noticed that this unidirectional current is of double the frequency of the supply and of small amplitude.

With a 3-phase supply a direct current of still more uniform value would be obtained.

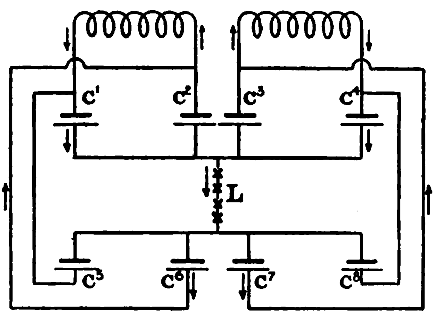

FIG. 5.

The connections for a 2-phase circuit are shown in Fig. 4. C_1, C_2, C_3, C_4, C_5, C_6, C_7, and C_8, are the cells of which the thin line represents the aluminium plate and the thick line the lead plate, and L is the load. The direction of the current is shown by the arrows. If the "valve" has been left standing any length of time it will have to be "formed" before it can be used. This consists in forming the valve film over the aluminium surface, and is effected by connecting the valve

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across the A.C. mains in series with a resistance, and gradually cutting the resistance out as the current falls. The formation takes only a few minutes.

Characteristics of the Electrolytic "Valve" System—

Losses.—The losses in the system are in two places only, viz. :—

1. The loss in the transformer, if one is used, which varies from 6 to 10 per cent. according to the size.
2. The loss in the cells, which manifests itself in the form of heat, and this is the great trouble with electrolytic "valves," there not being a great deal of cooling surface and it being essential that the temperature be kept below 50° C. Therefore the cooling device has to be supplied.

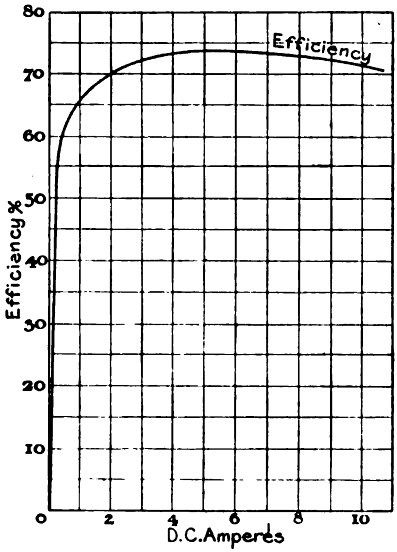

FIG. 6.

Power Factor.—The power factor of the system is over 90 per cent.

Limitations—

Voltage.—The electrolytic "valve" has rather a low voltage limit, this being the critical value of the E.M.F. mentioned above, *i.e.*, the E.M.F. which causes the crystallisation of the "valve film," and this value varies to a certain extent with the temperature. The "valves" show their maximum efficiency at 140 volts, and they should not be used on any higher voltage, as the efficiency rapidly falls off above this value.

Current.—Theoretically there is no limitation to the current, but practically greater trouble is experienced in keeping the larger sizes

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cool than is experienced with the smaller sizes. The price list issued by Mr. H. Snowdon, the sole maker of the Nodon "Valve" in England, contains quotations for a 100*a* size, and Mr. Snowdon informed the author that he had seen a 300*a* "valve" in France.

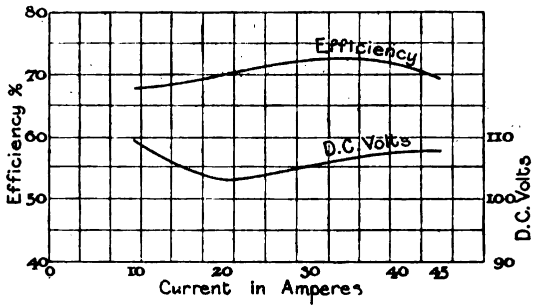

FIG. 7.

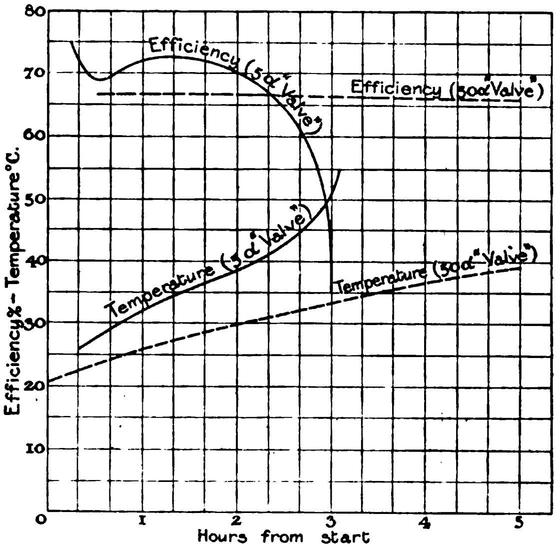

FIG. 8.

Frequency.—The "valves" appear to be little affected by the frequency, at least up to frequencies of 200 ∿ per second.

Efficiency.—Since practically the only loss is a C^2R loss, the efficiency is very nearly constant, and its value appears to be between 65 and 75 per cent., though in some cases it is a little higher.

Fig. 6 shows a test of a 5 Nodon "Valve" at 100 volts made by

Mr. A. C. Jolley * at Northampton Institute, E.C. It will be noticed that the efficiency rises almost instantaneously to a value of 60 per cent., and after that it rises gradually to a maximum of 73·5 per cent. at full load. The "valve" was overloaded 100 per cent., and the efficiency had then only fallen to 71·5 per cent., but most probably the experiment was finished quickly before there was time for the temperature to rise.

Fig. 7 shows a test of a 30*a* Nodon "Valve" at 140 volts made by Mr. G. W. Partridge at the Adelphi Station of the London Electrical Supply Corporation, and published in the *Electrical Times* (November 5, 1903). The maximum efficiency was 72·5 per cent. at about full load, and it fell to 70 per cent. at 50 per cent. overload.

With regard to the effect of temperature on the efficiency of the Nodon "Valve," Fig. 8 shows two tests of heating, one of a 5*a* and one

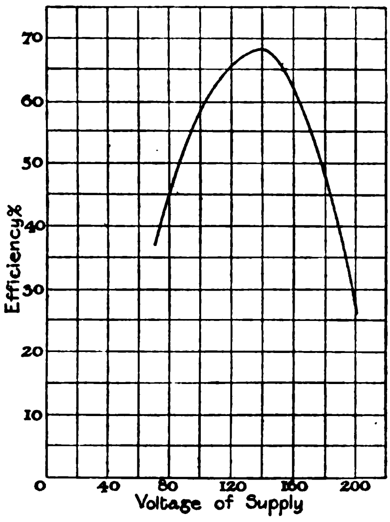

FIG 9.

of a 50*a* "valve" during a period of continuous use at full load for some hours. The full-line curves show the results of a test on a 5*a* "valve," by Mr. A. C. Jolley,† and the great rise of temperature shows that the "valve" was really too small for its output, and that the test shown in Fig. 6 was finished before there was time for the temperature to rise. The test extended over three hours, and by that time the temperature had risen to 51° C., and the efficiency had fallen to 35 per cent. From this curve it is seen that so long as temperature is kept below 40° C. the efficiency does not vary a great deal, but after this point the efficiency falls off rapidly. The dotted-line curves show a test on a

* *Electrician*, vol. 57, p. 998, 1906. † Ibid.

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50*a* "valve" by Mr. H. Boot.* The temperature rose in five hours to 40° C., and the efficiency was practically not affected, it remaining nearly constant at 66·5 per cent. This test includes all losses in the transformer and cooling fan.

Fig. 9 shows the variation of the efficiency with the voltage of supply of a 5*a* Nodon "Valve." † The efficiency is seen to reach a maximum, which in this case is 68 per cent. at 140 volts, and after this to fall off rapidly, until at 200 volts it is only 26 per cent. This is due to the crystallisation of the "valve film," which appears to commence very soon after 140 volts.

Life.—No data are at present at hand regarding the life of the Nodon "Valve."

Sizes—

Voltage—Current.—The Nodon "Valve" is made in sizes of from 1 to 100 amperes, and may be used on circuits of 50 volts to 140 volts and of any reasonable frequency.

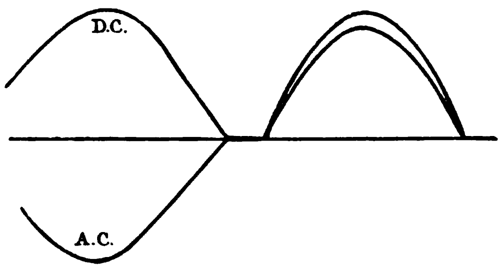

FIG. 10.

Fig. 10 shows an oscillograph record of the current curves of a 5*a* Nodon "Valve" on a non-inductive resistance and at 50 ∿ per second.

THE MERCURY ARC "VALVE."

The second type of valve to be discussed is one depending for its action on the property of ionised mercury vapour, of conducting electricity in one direction only, and is usually called the mercury arc rectifier, or the Cooper-Hewitt rectifier, after the inventor of the well-known arc lamp.

Theory of the Mercury Arc "Valve."—The action of the Mercury Arc "Valve" depends on the fact that current flows in an arc in mercury vapour only so long as the ionisation process is going on at the cathode surface, *i.e.*, only so long as there is a stream of conducting vapour in the space between the electrodes. Therefore an arc cannot start by itself, and to start it one of three methods must be employed, either—

* *Electrical Review*, vol. 56, p. 211, 1905.
† Jolley, *Electrician*, vol. 57, p. 1000, 1906.

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(1) The terminals must be brought together, thus starting a flow of current, and then drawn away from each other, as is done in nearly all arc lamps; or,

(2) The voltage must be increased to such an extent that a spark is able to jump across the gap and thus start the flow of cathode vapour; or,

(3) By supplying a conducting stream of vapour from another arc.

Description of the "Valve Tube."—The arc is formed in a glass tube usually called the rectifier tube. Two tubes, such as would be used on a single-phase supply, are shown in Fig. 11. Each is an exhausted glass vessel having two graphite anodes A, A, and a mercury cathode B. C is a small cup of mercury used as a starting electrode. Connections to the electrodes are made through pieces of platinum fused

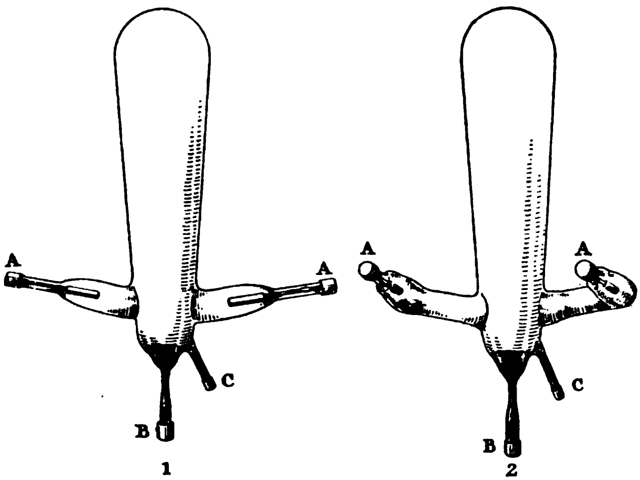

FIG. 11.

into the glass. Tube No. 1 is the 100 volt type, and is used on D.C. voltages of 45 volts to 150 volts. No. 2 is the 200 volt type, and is used on D.C. voltages of from 110 volts to 250 volts. Tubes should never be used above their rated voltage. If used at a lower voltage they may be hard to start, but otherwise will be satisfactory. It will be noticed in tube 2 that the glass projections containing the anodes bend out in a plane away from the plane of the tube, and this is to prevent arcing between the two anodes.

Description of "Valve" System.—The apparatus is primarily designed for a frequency of 60 ∿ per second, but may be used on other frequencies, and is arranged as shown in Fig. 12. The "valve tube" is marked X. The two anodes, M and N, are connected to the terminals of a constant-current transformer, AB, through reactive coils, G and F. The auxiliary anode for starting the arc (not shown in the

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figure) is supplied from a small constant-potential transformer. When the main arc is started the auxiliary arc is switched out. The mercury cathode O is connected to one end of the load L, through a reactance coil H, and the other end of the load is connected to the middle point C of the secondary of the transformer AB.

Mode of Operation.—Now if we imagine an instant when the current in the secondary of the transformer is tending to flow from A towards B, it will flow round the circuit shown by the dotted arrows (--->), viz., from B through reactance coil F to the anode N, thence through the tube to the cathode O, from O through the coil H to the load, and from the load to the middle point C of the transformer. Now imagine

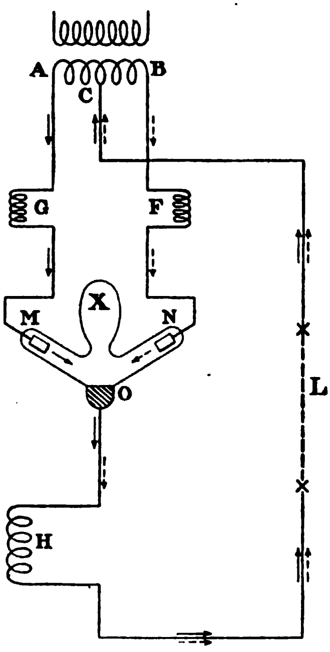

FIG. 12.

the next instant; when the current in the transformer tends to flow from B to A it takes the path shown by the full-line arrows (—>), viz., through reactance G, anode M, cathode O, load L, and back to the transformer at C. Thus, if the reactance coils were not used, it is seen that, providing the arc were able to start again at the end of a half cycle at the other anode than which had just been used, the current flowing through the load would be a unidirectional pulsating current with two points of zero value in each cycle, as shown in curve C, Fig. 1. As the minimum voltage required to maintain a mercury arc is 18 volts,

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this form of wave is impossible, and some means must be used to prevent the current flowing through the anode from reaching zero value until after the arc has been started at the other anode, as even with a frequency of 10,000 ∿ per second the arc will go out at the end of the first half wave.

The means used to prevent the current reaching a zero value too soon are the reactive coils G and F, their action being that at the beginning of each half-cycle they charge up, and discharge themselves at the end of the half-cycle, thus causing an overlap of the two currents flowing through the cathode O, *i.e.*, each half current wave lasts for more than 180°, and the resultant current flowing through the cathode never reaches a zero value, as shown in Fig. 13. A is the supplied E.M.F., B are the currents flowing through the cathode, I. from one anode, and II. from the other anode. The current B1 starts at the zero value of its E.M.F., A1, and rises slower than it would were no reactance present, it following essentially the exponential curve of a

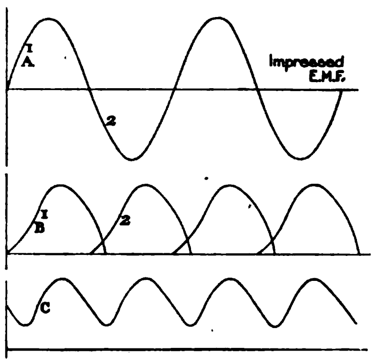

FIG. 13.

starting current. The intrinsic energy is returned to the circuit as the end of the half wave is approached by continuing the current wave beyond its corresponding E.M.F. wave, as shown in B, Fig. 13.* Mr. C. P. Steinmetz gives a value for this overlap in one case as being 44° beyond the end of the half wave. By adding together the two curves B1 and B2 the curve C is obtained, and this is the total current flowing through the cathode and the load. It will be noticed that the current is one of varying amount, but is unidirectional, the overlap in this case being only about 32°. With a very little more overlap the current produced would be very much smoother. The reactance coil H, which is in the D.C. circuit, is to regulate the amount of variation of the unidirectional current. Since the current through the cathode never reaches a zero value, the arc is continuous at the cathode, which therefore gives a constant stream of vapour.

* *Transactions, Amer. Institute of Electrical Engineers*, vol. 24, p. 371; 1905.

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Characteristics of the Mercury Arc "Valve" System.—The characteristics of the system, such as efficiency, power factor, regulation, etc., are essentially those of the constant-current transformer feeding the tube.

Losses.—The losses in the valve system are as follows:—

1. The loss in the transformer, which varies from 6 to 10 per cent., according to the size.
2. The C^2R and hysteresis loss in the A.C. reactive coils. This loss is small, and can be further reduced by making the coils larger, and therefore more costly.
3. The loss in the valve tube, which is made up of two parts: the leakage loss from one anode to the other, and a constant drop of 18 volts, irrespective of the load; the mercury arc voltage. The leakage loss is small, but increases with the

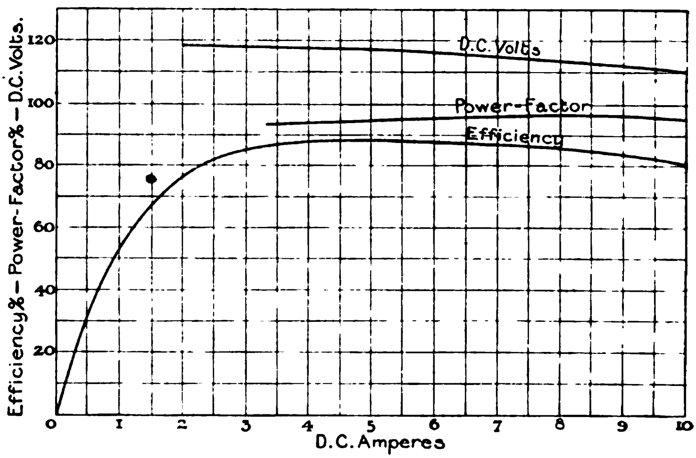

FIG. 14.

load, and the 18-volt constant drop is very small when working on fairly high voltage. It is only 1·8 per cent. for a supply of 1,000 volts.

4. The C^2R and hysteresis loss in the D.C. reactive coil. This loss is negligible.

The variation of the unidirectional current supplied can be regulated, as mentioned, by the D.C. reactive coil, but it may also be regulated by the reactive coils placed in the A.C. circuit.

Power Factor.—The power factor of the system is lowered by the reactive coils, but is raised by the non-inductive character of the load, and varies from 90 to 95 per cent.

Limitations of the Mercury Arc "Valve" System—

(1) *Voltage.*—With high voltages a difficulty is experienced in leakage between the anodes, technically known as "arcing of the rectifier,"

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but it is claimed that this has been overcome, and in the opinion of Mr. C. P. Steinmetz it is not probable that a voltage limit of rectification will be reached, as they have succeeded in rectifying 36,000 volts at small current. The rectified voltage is slightly under half the voltage of supply.

(2) *Current.*—Theoretically there is no limit to the current which can be rectified, but practically there is a difficulty in introducing large currents into an exhausted glass vessel and in dissipating the energy wasted in the "valve" in the form of heat. It appears to the author that there would be some difficulty in fusing the large pieces of metal, to carry a heavy current, successfully into the glass bulb, but it is claimed that they have been made for 100*a*.

Efficiency of the Mercury Arc "Valve" System.—Since the loss in the valve tube is practically constant, the efficiency varies practically with the direct current voltage. Fig. 14 shows some tests on a 10*a* set, and Fig. 15 some tests on a 30*a* set made by Dr. Weintraub.* As will be seen in Fig. 14, the efficiency is practically constant from quarter

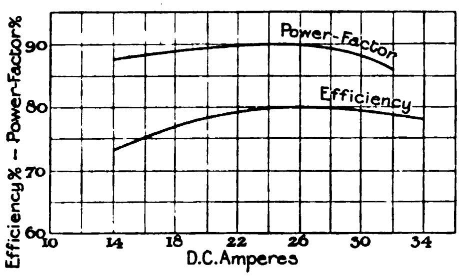

FIG. 15.

load to full load, and in the 10*a* size is about 82 per cent. at full load, and in the 30*a* size 80 per cent. The D.C. voltage of the 10*a* valve was 110 at full load. These tests were most probably made only on the valve tube alone, so that the efficiency of a complete set at this voltage would probably not be more than 75 to 80 per cent.

Fig. 16 shows a test of a 3·8-k.w. set supplying 3·8*a* at 1,000 volts D.C. to mercury arc lamps for street lighting in Schenectady, made by Mr. J. R. Hayden, of Schenectady, U.S.A., and published by Mr. C. P. Steinmetz.† In this case the power factor is only 75 per cent. The efficiency rises to a value of 80 per cent.

Fig. 17 shows a test of a 14-k.w. set supplying 4*a* at 4,260 volts D.C. to magnetite arc lamps for street lighting in Schenectady, made by Mr. R. Fleming, of Lynn, U.S.A., and published by Mr. C. P. Steinmetz.‡ The impressed voltage was 11,800. The efficiency in this case rises to a value of 92 per cent.

* *Electrical World*, vol. 45, p. 1031, 1905.
† *Transactions, Amer. Institute o Electrical Engineers*, vol. 24, p. 380, 1905.
‡ Ibid, p. 383.

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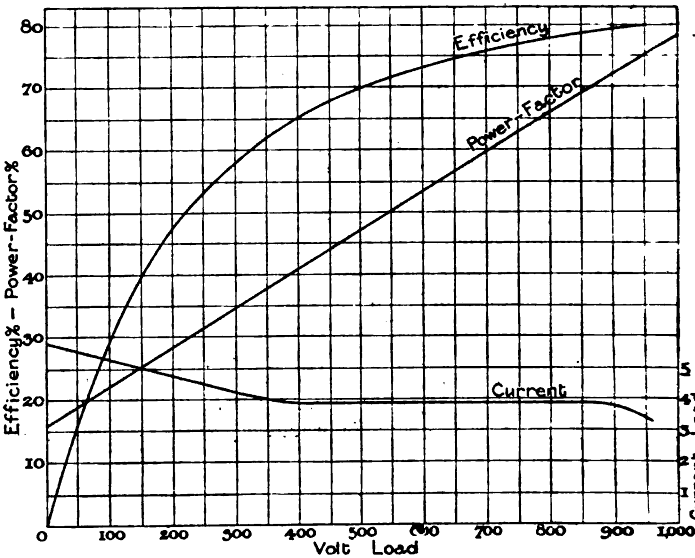
Efficiency
Power-Factor
Current
Efficiency% - Power-Factor%
Current Load
Volt Load
0
100
200
300
400
500
700
800
900
1,000
10
20
30
40
50
60
70
80
1
2
3
4
5

FIG. 16.

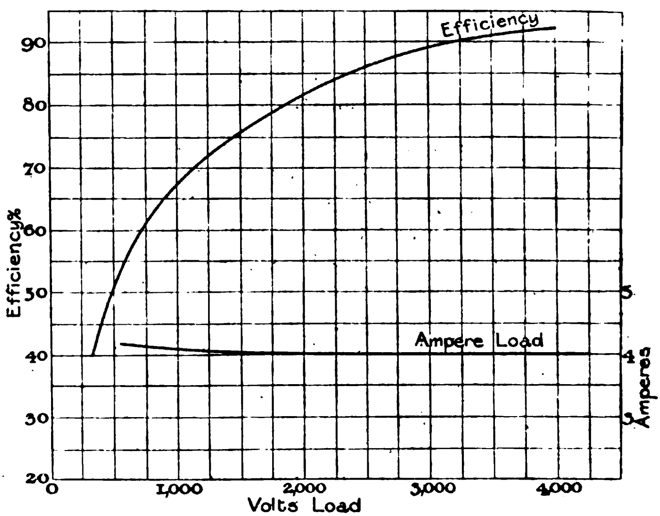
Efficiency
Ampere Load
Efficiency%
Amperes
Volts Load
0
1,000
2,000
3,000
4,000
20
30
40
50
60
70
80
90
3
4
5

FIG. 17.

Sizes—

(1) *Voltage.*—It is mentioned above that the "valve" can be made for any voltage, but the standard outfits are made for 110 volts and 220 volts alternating. The D.C. voltage may be said to range from 20 per cent. to 50 per cent. of the applied A.C.

(2) *Current.*—The "valve" is furnished in three standard sizes, 10*a*, 20*a*, and 30*a*.

(3) *Frequency.*—The frequency is of little importance within limits, the "valves" acting satisfactorily on a frequency of 25 ∿ or 125 ∿ per second, though they are designed for a frequency of 60 ∿ per

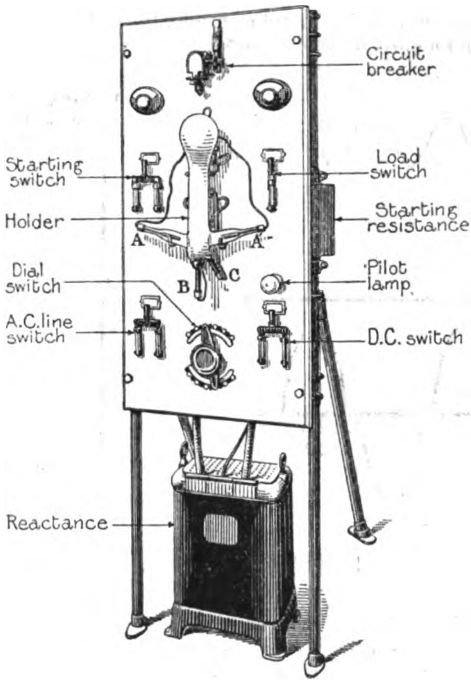

Fig. 18.

second. The D.C. voltage varies slightly with the frequency, it being very slightly lower at 125 ∿ than at 60 ∿.

The limit appears to be not much above this, probably about 80 to 100 k.w. per tube, *i.e.*, 10*a* at 10,000 volts D.C. at the most, though several tubes may be used to increase a necessary supply.

The set suitable for a garage, including the "valve" tube, the reactances, voltmeter, ammeter, and the necessary switches, etc., are mounted on a panel, as shown in Fig. 18. This type of apparatus is manufactured by the General Electric Company, of America, and the British Thomson-Houston Company, of Rugby. The panel is 48 ins. ×

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24 ins., and the floor space occupied by a set is 24 ins. × 18 ins., and it is 76 ins. high.

Life.—The only part of the "valve" system that wears out is the tube. The following results* have been obtained:—

10*a* size	4,500 hours' life.
20*a* "	2,500 "
30*a* "	1,400 "

Fig. 19 shows some oscillograph records of the current curves of a mercury arc "valve" published by Mr. Wagoner.†

There are also types of "valves" which have a much more limited sphere of usefulness, as the Fleming Oscillation "Valve," etc. Some of these will now be very briefly described.

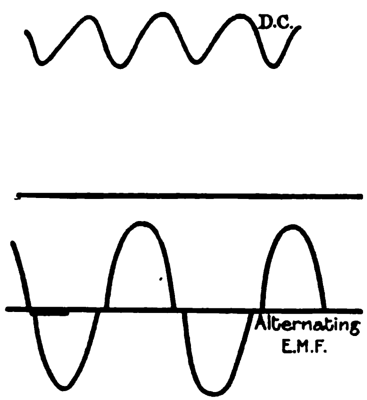

FIG. 19.

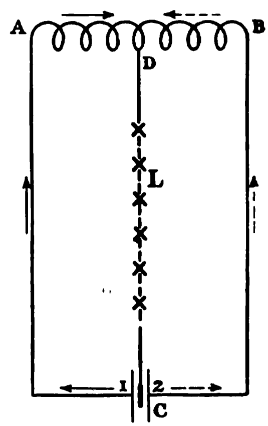

FIG. 20.

(1) *The Churcher*‡ "*Valve.*"—This is an electrolytic apparatus, and depends for its action on exactly the same principle as the Nodon "Valve." The apparatus differs from the Nodon type in that it has, for a single-phase circuit, two aluminium cathodes and one lead or platinum anode suspended in the same cell. By this means only one cell is required to rectify an alternating current, instead of four as in the Grätz arrangement of the Nodon "Valve." The connections for a single-phase supply are shown in Fig. 20. A B is the secondary of a transformer and is tapped at the middle D. L is the load and C is cell, of which the long thin lines are the aluminium plates and the short thick line the lead plate. The aluminium plates 1 and 2 are connected to the extremities of the transformer secondary, the lead plate being joined to the load L, which is also connected to the middle point D of the transformer.

* Wagoner, National Electric Association Convention, 1905.
† *Ibid.*
‡ *Electrical World*, vol. 44, p. 308, 1904.

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When the current in A B tends to flow from A to B the full-line arrows (→) show its direction, *i.e.*, the middle point D, through the load L to the lead plate of the cell C, then to the aluminium plate 1 and back to A. When the direction of the current reverses and tends to flow from B to A, the dotted arrows (⇢) show its course, *i.e.*, through D, load L, aluminium plate 2, back to B.

It is stated that the practical limit of one cell of the Churcher type is 50 volts D.C., or 130 volts across the active electrodes.

(2) *The De Faria* * " *Valve.*"—The De Faria " Valve " is electrolytic, the electrodes being a hollow cylinder of aluminium and a hollow cylinder of lead, the whole being placed in an electrolyte contained in a hard rubber vessel. The electrolyte is a solution of sodium phosphate made of 1 kg. of the salt to 8 litres of water.

The aluminium plate has to be formed, *i.e.*, the insulating film has to be formed over it, and this is done by connecting the cell to the A.C.

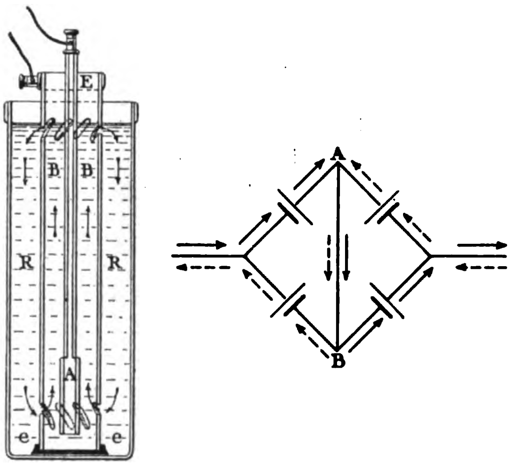

FIG. 21.

mains through a resistance and then gradually cutting this out as the current lessens. This formation has only to be done once. There is an interesting method of keeping the cell cool. Holes are made round the top and bottom of the lead cylinder (Fig. 21), the heat then causing the hot electrolyte to rise inside the cylinder, pass through the holes at the top and descend outside the cylinder. It is claimed that the cooling action thus obtained is sufficiently rapid to operate with a current density of 8*a* per square decimetre of aluminium surface.

The efficiency of a 10*a* size is 60 per cent., rising to 65 to 70 per cent. in a 25*a* size.

The sizes given are for a

10*a* size at 110 volts, 90 cms. high, 48 cms. wide, and 48 cms. long.

* *La Revue Electrique*, vol. 6, p. 296, 1906.

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and for a

25*a* size at 110 volts, 60 cms. high, 52 cms. wide, and 110 cms. long.

(3) *The Büttner* * *" Valve."*—The Büttner "Valve" is an electrolytic apparatus, it having a magnesium aluminium alloy as a cathode and another metal as anode (most probably lead or iron) suspended in a solution of ammonium borate. Mr. Büttner claims that ammonium borate is better than ammonium phosphate, as it does not attack iron, whereas the latter does, and, also, that it will keep in working condition for a longer period than the latter.

(4) *Pawlowski* † *" Valve."*—The novelty of the "valve" invented by Pawlowski, which is also an electrolytic apparatus, is in the use of a solid electrolyte. The "valve" consists of a plate of copper coated with a layer of crystalline hemisulphide of copper, which has to be carefully

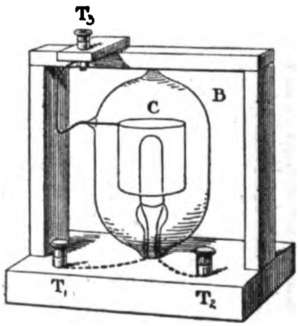

FIG. 22.

prepared, placed in intimate contact with a sheet of aluminium. The "valve" must be formed before it is ready for use, and this is done by passing an alternating current through it until the sparking which takes place at first ceases. The hemisulphide of copper is best prepared by melting a mixture of sulphur and copper without admission of air. The combination allows current to pass only from the aluminium to the copper.

All the "valves" described above are suitable for comparatively low voltage low-frequency work, but there are "valves" which work with the high voltage of the secondary discharge of an induction coil, or may be used to rectify currents of such high frequency as Tesla currents. Some of these will now be briefly described:—

(1) *The Spark-gap* ‡ *" Valve."*—In this apparatus two paths are arranged, for the discharge from an induction coil, consisting of a point and a ball terminal arranged in opposite directions. In one path is

* *Centralblatt für Accumulatoren*, vol. 6, pp. 66, 97, 1905.
† *Electrical Review, N.Y.*, vol. 49, p. 554, 1906.
‡ *Physical Society Proceedings*, vol. 20, p. 177, 1906.

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placed the X-ray tube, and its resistance is balanced by making the other path slightly longer. When the discharge is in one direction it will pass through the tube, and when in the other direction it will pass across the air-gap in the other path.

(2) *The Fleming* Oscillation "Valve."*—This "valve" consists of a carbon filament glow-lamp in which the carbon loop is upheld in the centre of the exhausted glass bulb B, Fig. 22, in which a small cylinder of nickel C surrounds the filament, a connection being made to this through a platinum wire sealed into the glass bulb (see Fig. 22). When the carbon filament is made to glow at a bright incandescence the apparatus conducts electricity only in the direction from the cylinder to the filament, the explanation being that the incandescent carbon emits negative ions or electrons. M. A. Wehnelt has studied the action of other substances as a cathode in a vacuum "valve," and he has proposed to employ the heated incandescent oxides of calcium, barium, and strontium as such. It is possible to obtain the effect at atmospheric pressure, but the advantage of using a vacuum is that the

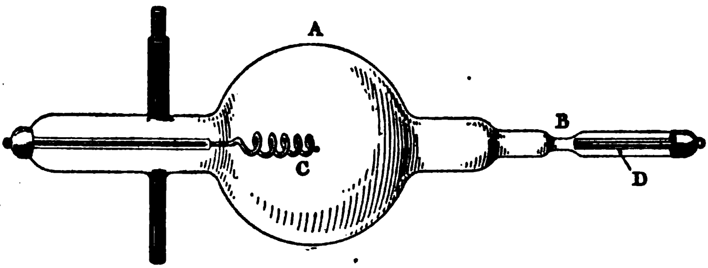

FIG. 23.

electrons are shot out to a greater distance, and therefore the metallic plate can be placed a greater distance from the filament and thus kept cool, as it is essential that it should be cool. The filament is made to take 2 to 3 amperes at 12 volts, and is heated by a passing current from a small battery.

The valve passes current at a fraction of a volt, and it is extremely useful in detecting high-frequency currents by means of a delicate galvanometer, *i.e.*, by placing one in series with a galvanometer and the circuit in which the oscillations take place.

(3) *The Audion† "Valve."*—The Audion was invented in 1900 by Lee de Forest as a wireless-telegraphy receiver of great delicacy. It is practically the same as Fleming's Oscillation "Valve."

(4) *The Wright "Valve."*—This valve was, the author believes, invented by a Mr. R. S. Wright, and it is therefore given the above name. Fig. 23 shows a photograph of one of the valves. It consists of an exhausted glass bulb A, which is drawn out in two

* *Proceedings of the Royal Society*, vol. 74, p. 476, 1905.
† *Transactions, Amer. Institute of Electrical Engineers*, vol. 25, 1906.

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opposite places. Into these two elongated portions of the tube the electrodes are fastened, C being the anode, which consists of a spiral of round aluminium wire, and D the cathode, which is an aluminium rod with a flat end.

If the negative ions or electrons emitted by the cathode are unable to reach the anode, no current will flow between the electrodes, and it is by preventing the electrons emitted by the electrode, then acting as cathode, from reaching the other electrode that the tube is made conducting in one direction only. Normally the current flows from the spiral electrode C to the flat electrode D, for then D, being the cathode, emits electrons along paths normal to its surface, *i.e.*, in a

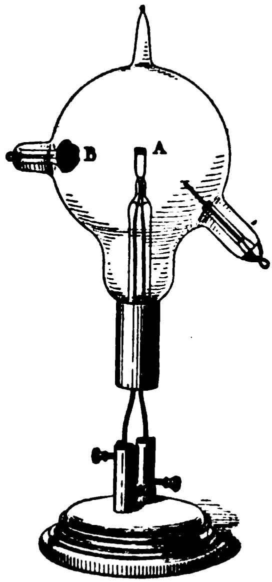

FIG. 24.

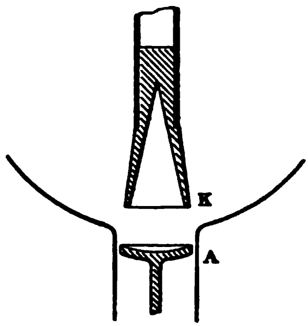

FIG. 25.

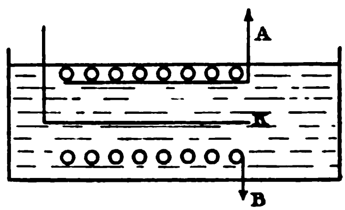

FIG. 26.

parallel beam, which reaches to the spiral anode C, and thus current can flow from the spiral to the flat-faced electrode. Now, when the spiral tends to become the cathode it emits electrons normally to its surface, and these therefore spread out in all directions, very few of them reaching the electrode D. Thus current is unable to flow from the electrode D to the spiral C. Fewer cathode rays from the spiral, when it tends to become cathode, are prevented from reaching the electrode D by thinning the tube down and thus making the path narrower just in front of this electrode, as is shown at B.

(5) *The Wehnelt "Valve."*—This valve, invented by Professor Dr. A. Wehnelt, depends for its action on the emission of electrons from hot calcium oxide, as mentioned above. In Fig. 24, A is the cathode,

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consisting of a piece of platinum with a spot of calcium oxide on it, and B is the anode, both of which are enclosed in an exhausted glass vessel. When the platinum is heated, this being effected by passing a current from a secondary battery round it, the oxide emits electrons copiously, and thus a current is only able to flow from electrode B to the platinum A.

(6) *The Koch* * *"Valve."*—This valve has been called the Koch "Valve" because Mr. Koch describes it, though the author is not sure that this gentleman invented the apparatus. In Fig. 25, A is the anode, consisting of a hollow-surfaced piece of metal, and K is the cathode, consisting of a piece of metal with a funnel-shaped gap turned in the end, enclosed in an exhausted glass vessel. When the current tends to flow from K to A, the cathode rays produced by A are brought to a focus by the hollow surface of A at a point in the funnel-shaped opening, and this prevents any current flowing from K to A; but when the current tends to flow from A to K, electrons are emitted by K which reach A, and thus current is able to flow from A to K.

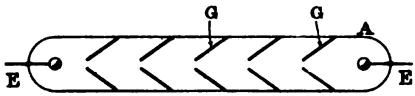

FIG. 27.

(7) *The Grisson* † *"Valve."*—The Grisson "Valve" is an electrolytic apparatus having a sheet of aluminium as cathode and a sheet of lead as anode, placed in an electrolyte of a solution of sodium carbonate. Water is circulated through tubes to keep the apparatus cool. In Fig. 26, A is the aluminium cathode, K is the lead anode, and B shows a section through the cooling-tubes.

A modified form, which presents many improvements, of this "Valve" is now being made by Mr. Isenthal of Mortimer Street, W.

(8) *The Holtz "Valve"* was invented by Holtz, and consists of an exhausted glass vessel A (Fig. 27) in the form of a tube, having the electrodes E E′ sealed in at the ends. A number of glass funnels G are arranged, pointing all one way, and so that they fit the tube. Now, when the current tends to flow from E′ to E, the cathode rays given off by E cannot reach E′ owing to the small opening at the bottom of the funnel, and therefore current is unable to flow, but when the direction is reversed the cathode rays from E′ can pass down the funnels, thus allowing current to flow from E to E′.

* J. F. Koch, *Elektrotechnische Zeitschrift*, vol. 27, p. 705, 1906.
† *Central-Zeitung für Optik und Mechanik*, vol. 28, p. 95, 1907.

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THE INDUCTION MOTOR.

By Robert Rankin, A.G.T.C.

(Abstract of Paper read before the Glasgow Branch of the Students' Section.)

Having briefly described the production and chief characteristics of one, two, and three phase currents, the author proceeds to deal with their action when applied to induction motors.

Rotating Magnetic Field.—When polyphase currents are passed through properly spaced windings on an iron core, a rotating magnetic field is produced, and on this fact the working of induction motors depends.

If an iron ring is wound as shown in Fig. 1, and currents passed as

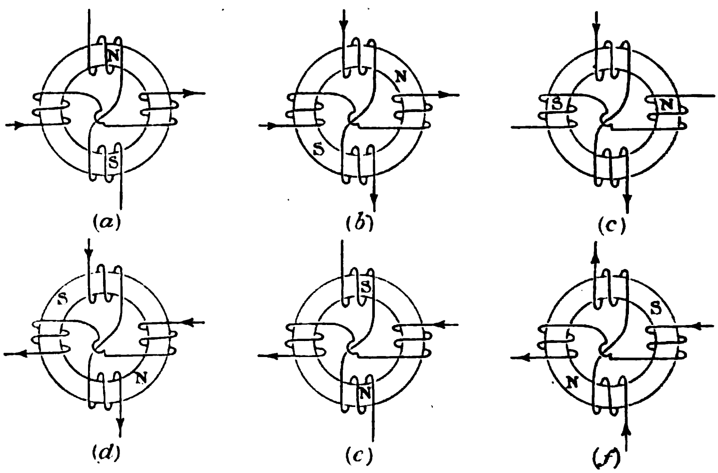

Fig. 1.

indicated by the arrows, then magnetic poles will be formed, the polarity being as shown in the various cases. If the changes take place step by step, as indicated by the figures, then the poles will travel round the ring, step by step, correspondingly. If the changes take place gradually the poles will rotate gradually.

This latter state of things would be brought about by connecting a 2-phase current to the apparatus, one phase to each pair of coils. In the case of 2-phase currents, one phase has its maximum current

value when the current in the other is zero. This would be represented by (*a*) in the figure, and as the currents in the two phases assumed their periodic values the different states of things would be represented by the other figures in rotation. If instead of putting on four equally spaced coils we had put on three equally spaced coils, the same effect would have resulted as regards the magnetic field.

Each of these methods gives a 2-pole winding. If it is desired to have a multipolar winding, then more sets of coils will require to be put on, each set giving one pair of poles.

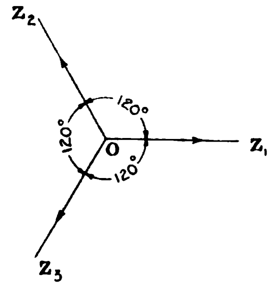

FIG. 2.

Consider the case of a 3-phase current and set off the lines OZ_1, OZ_2, and OZ_3 (Fig. 2) to represent the maximum value of the flux in the directions in which it attains a maximum.

Let Z = maximum value of the flux.

Let z_1, z_2, and z_3 = instantaneous values of the flux in the various directions. Then—

$$z_1 = Z \sin \theta,$$
$$z_2 = Z \sin (\theta - 120°),$$
$$z_3 = Z \sin (\theta + 120°),$$

where θ is the phase angle.

To find the resultant field, resolve each into its vertical and horizontal components. Adding these we get the total vertical component—

$$= \frac{3}{2} Z \cos \theta.$$

Similarly total horizontal component

$$= \frac{3}{2} Z \sin \theta.$$

Resultant

$$= \frac{3}{2} Z = \text{constant}.$$

Let ϕ = angle resultant makes with vertical.

Then $\tan \phi = \dfrac{\text{total horizontal component}}{\text{total vertical component}}$.

$$= \frac{\frac{3}{2} Z \sin \theta}{\frac{3}{2} Z \cos \theta} = \tan \theta.$$

$$\therefore \phi = \theta.$$

Hence ϕ varies at the same rate as θ and consequently the resultant will make one revolution during one period of the supply current.

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This, as has been said, is for a 2-pole stator. For a multipolar stator the speed of the rotating field will be given by

$$\text{revs. per second} = \frac{\text{frequency per second}}{\text{number of pairs of poles}}.$$

An induction motor, like a continuous-current machine, consists essentially of two parts—a rotating part and a stationary part. The rotating part is called the rotor and the stationary part is called the stator. The rotor usually consists of a number of conductors carried by a laminated iron core, and so connected as to form a number of complete electrical circuits. The core of the stator is also of laminated iron, and its windings are connected to the polyphase supply circuit.

When the rotor circuits are closed, a current flows and a reaction takes place between it and the revolving field, and the conductors on the rotor will be urged in the direction of the rotation of the field. The torque thus produced will be proportional to the product of the flux and the current induced in the bars.

Types of Slots.—Parallel slots, open at the top, have the advantage that the coils to be put therein may be former wound. In the case of the closed or partly closed slots, the winding must be done by hand, and hence the danger of damaging it is much greater than in the case of coils wound on formers and then placed in position. Also in the case of former wound coils repair is relatively easier.

However, with open slots the effective area of the air-gap is much less than it is in the other case. The flux will issue from the iron of the stator and cross the air-gap, and hence with open slots a certain amount of area which would be iron area if the slots were totally enclosed will be unavailable, since it is taken up by the slot. With wholly closed slots all the area of the air-gap will be effective for flux-carrying purposes. This means that in the case of the open slots the magnetic reluctance of the air-gap is greater than it is in the case of the closed slots, and hence a greater magnetising current is required.

The slots should be made as shallow as practicable, and the teeth should be of narrow cross-section. In this way the E.M.F. induced in the winding by the leakage field is diminished, and the reluctance of the path of the leakage lines through the teeth is increased by the high saturation of the narrow teeth. Perhaps the best form of slot is the partly closed form, which gives a compromise between the advantages and disadvantages of the other two types.

Slip.—If the conductors rotate with the same speed as the field there will be no E.M.F. induced, since they will cut no lines of force. If the rotor ran at such a speed that no E.M.F. was induced in the bars, the rotor would be said to be running at the speed of synchronism. This it can never do, since there is always friction loss. The difference between the speed of the rotating field and the rotor is commonly called the rotor slip. This is hardly correct. It would be more correct

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to say that the slip is proportional to the difference between these two speeds.

There are several definitions of slip, and this often leads to some confusion. The meaning of slip may be more clearly understood from the following explanation :—

Let $\sim_s$ = frequency of stator current.
„ $\sim_r$ = frequency of rotor current.
„ n_r = revolutions per second of rotor.
„ n_s = revolutions per second of rotating field.
„ P = number of pairs of poles.

We have—

frequency = revs. per sec. × number of pairs of poles.

$$\therefore \sim_s = n_s \times P,$$

and

$$\sim_r = (n_s - n_r) P.$$

The correct definition of slip is the ratio $\frac{\sim_r}{\sim_s}$.

Hence we have—

$$S = \frac{\sim_r}{\sim_s} = \frac{(n_s - n_r)}{n_s} = 1 - \frac{n_r}{n_s}.$$

From this it will be seen that the slip is zero when $n_r = n_s$. Hence the synchronous speed of the rotor is $\frac{\sim_s}{P}$.

It is clear that the rate of cutting of magnetic lines is proportional to the slip, and hence the E.M.F. varies as the slip, and similarly the current. The torque depends on the strength of the current, and hence for a given rotor the slip is proportional to the torque. That is, the slip increases with increase of load. Also, since the slip is proportional to the torque, and the torque to the current in the rotor bars, it is evident that the slip is also proportional to the resistance of the rotor. To produce a given torque a certain current has to flow through the rotor bars. The flux being practically constant, the E.M.F. generated in the rotor bars, and hence the current flowing through them, will depend on their speed relative to the rotating flux; that is, the slower the speed the greater the current which flows. If the rotor resistance is increased the rotor will reqaire to run more slowly in order to have the required current. This fact is made use of in the speed regulation of induction motors.

Types of Rotor.—There are two types of rotor : (1) squirrel-cage type and (2) wound type.

(1) The squirrel-cage rotor consists of a number of insulated copper bars embedded in a laminated iron core and short-circuited at the ends. The bars are fixed to a stout copper ring, and they may be either bolted or soldered to it or the ring may be of cast copper brazed

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on to the ends of the wires in the foundry. It will be seen that the resistances of a rotor of this type will be very small, and this fact limits the use of pure squirrel-cage motors to cases in which the motor starts on no load or on light load, except in the case of the smaller sizes of motors—that is, motors, say, under 5 H.P.

When the polyphase current is switched on to the stator the rotor is at rest. The rotating field whirls round with its full-speed, and consequently the bars of the rotor cut all the lines of force, thus having a high E.M.F. induced in them. The resistance being so very low, a very heavy current will flow through the rotor. To limit this current there is nothing but the magnetic leakage between the stator poles and the lowering of the pressure on the stator terminals, which is the result of the heavy current which will be taken by the stator. This heavy starting current is a serious drawback to this type of motor. For a motor starting at no load, the current taken from the mains at starting will be something like twice full load current; if the motor starts at full load, the current taken may be as high as four times the full load current. In the first case the heavy current will flow only for a very short time, as the motor will speed up almost immediately. In the second case, however, the duration of the current is longer, and the motor is liable to be burned out.

If we consider the action of the motor as simply being that of a transformer with a rotating secondary winding, the reason for the large starting current taken from the mains will perhaps be clearer. The stator winding will be the primary of the transformer. When the stator coils are connected to a supply of, say, V volts, an alternating flux will be set up in the iron laminations of the stator core. This flux will cause an E.M.F. to be set up in the secondary, and will also cause a back E.M.F. in the primary. The primary back E.M.F. will be very nearly equal to the impressed E.M.F. of V volts. The slight difference will be equal to the drop due to the resistance of the stator winding.

If the circuit of the secondary—that is, the rotor in our case—is open, then an E.M.F. will be induced in it practically bearing the same ratio to the primary voltage as the number of turns in the secondary bears to the number of turns in the primary. Immediately, however, the secondary circuit is closed, as it is in the case of a squirrel-cage rotor, a current will flow equal to the quotient of the secondary voltage and the virtual secondary impedance. This will be a large current, and as the effect of the secondary current is opposite to that of the primary current, the currents being practically in phase opposition, it will, to a great extent, reduce the magnetic flux due to the primary current, and hence the back E.M.F. of the primary will fall. This drop of the back E.M.F. will leave a greater difference between it and the impressed E.M.F., and hence a much greater current will flow through the stator coils in order to compensate for the weakening effect of the secondary current. This, then, is the cause of the large starting current taken by squirrel-cage motors.

Effect of Leakage Field.—The effect of the stator leakage field

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is exactly the same as if the self-induction of the stator coils were to be increased. It decreases the useful effect of the stator voltage and produces an increase in the lag of the stator current.

The great current in the rotor winding has the effect of increasing the magnetic reluctance of the path of the lines passing from stator to rotor in comparison with that of the path of the leakage lines. Hence the leakage field is greatly increased, and this has the effect of throwing the stator current very far out of phase, thus affecting to a considerable extent the pressure regulation of the system. For this reason it is necessary to limit the size of pure squirrel-cage motors in common use to about 5 H.P., especially if there are any lighting circuits connected with the system.

Since the leakage field of the motor acts in this way, it is desirable to have the air-gap as small as possible in order to reduce the magnetic reluctance of the path of the main flux. This, again, leads to trouble in the centring of the rotor. Since the air-gap is so small the rotor must be in an exactly central position relative to the stator, otherwise there may be a very strong unbalanced force, causing a large bending moment in the shaft. This has been investigated by J. K. Sumec, and he gives the following formula for the side pull due to bad centring :—

$$P = \frac{B^2}{8\pi} \times F,$$

where F is a factor depending on the dimensions of the motor.

$$F = S\frac{\varepsilon}{\delta} \cdot \frac{1}{\left\{1 - \left(\frac{\varepsilon}{\delta}\right)^2\right\}^{\frac{3}{2}}}.$$

P = side pull in dynes.
B^2 = mean square of induction at surface of rotor if rotor is exactly co-axial with stator.
S = surface area of rotor in square centimetres.
δ = length of air-gap.
ε = eccentricity of rotor relative to stator.

Another evil effect of bad centring is the setting up in the rotor of equalising currents in the same way as these wasteful currents are set up in the armatures of lap-wound direct-current machines. To get over this difficulty Osnos proposed to divide the short-circuiting end rings of the rotor into as many equal parts as there are pairs of poles on the stator. With this arrangement the same number of bars, connected to one of these divisions, is under the influence of a north pole as is under the influence of a south pole. The principle of this method is shown in Fig. 3, the stator poles being shown as they are simply for clearness. When the end rings are thus divided equalising currents can only flow between conductors on the same division of the ring, similarly situated with respect to similar poles.

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By the use of divided end rings these currents are greatly reduced, and in motors having eight or ten poles they are practically done away with altogether.

Returning to the question of the great starting current taken by induction motors, we see that the remedy lies in putting resistance in the rotor circuit at starting. This has led to the use of wound rotors, or, as they are sometimes called, slip-ring rotors, which are wound in a similar way to the stator, and made for a definite number of poles. However, some devices have been invented by which it is possible to

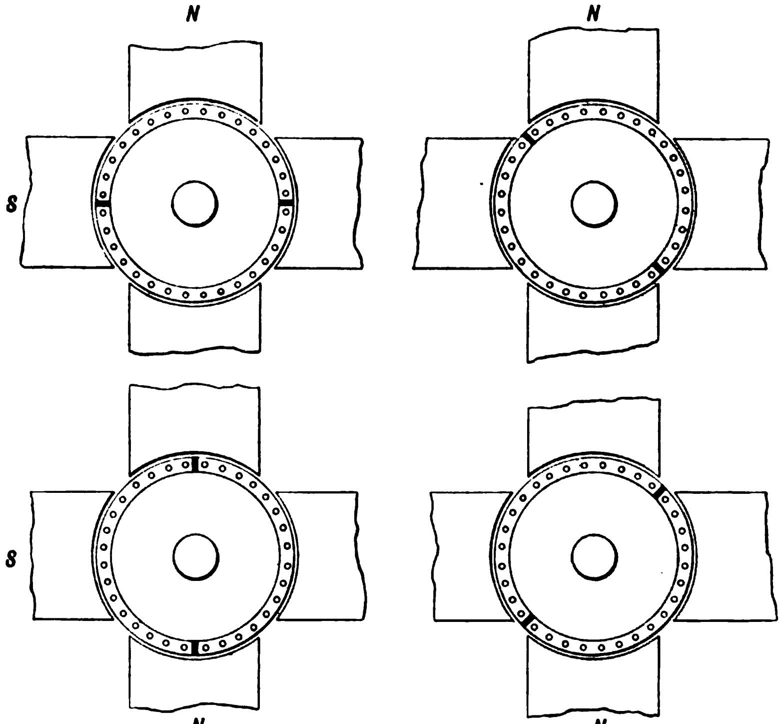

FIG. 3.

combine the simplicity of squirrel-cage rotors with a fairly large starting torque and a fairly small starting current.

The squirrel-cage motor may be made quite as satisfactory as the slip-ring type by the use of a suitable mechanical arrangement to apply the load after the speed has risen to a proper value, and besides it has a higher efficiency, and is capable of sustaining a greater overload than the other. The power factor is greater since, the rotor-bars being all short-circuited, the current in them varies in accordance with the flux. In the wound rotor only the free ends are short-circuited, the rest of the bars being in series, and hence the

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current is the same in all the bars of any phase, and does not follow the variations of the flux in the same way.

Methods of Starting Induction Motors.—It is not intended to enter upon a detailed description of all the various methods of starting these motors, but only to indicate how it may be done and how it is done in a few cases.

As has been already said, small motors, say, up to about 5 H.P., may be started by switching the stator windings directly on to the line, but motors of a larger size take much too great a current at starting by this method. All that is required, therefore, to start a small motor is a 3-pole single-throw switch.

For larger sizes a piece of apparatus called an auto-transformer or compensator is used at starting. By using this compensator the motor is supplied with current at the voltage necessary to start it light—that is, to overcome its own friction—instead of having the full line voltage

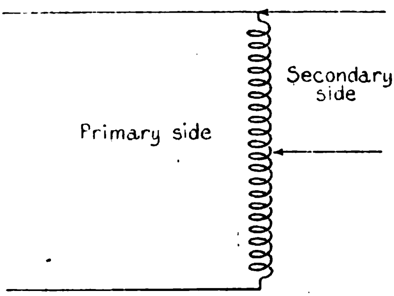

FIG. 4.

applied at its terminals. The compensator is really a transformer whose primary is connected to the line, and whose secondary is a part of the primary between the end and a tapping to which the wire from the motor is connected. Fig. 4 shows the principle of the compensator.

The next figure, Fig. 5, shows the method of using an auto-transformer with a 3-phase motor. When the throw-over switch is on the starting terminals the motor gets only a fraction of its normal voltage, but when it has run up to a proper speed the switch is thrown over to the other terminals, thus putting the motor directly on to the supply voltage.

Large motors sometimes, instead of having a compensator, have a step-down transformer of their own, taps being taken out of the secondary itself. This method has been considered by Mr. H. S. Meyer.*

Motors designed with delta or mesh connections may be started at a fairly low starting current by simply connecting the stator winding in star to begin with. This reduces the starting current to

* *Electrician*, vol. 49, pp. 307, 347, 394, 481, 526, 1902.

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a third of what it would be if the delta connections were thrown directly on to the line. This method has been employed by the Schuckert Company.

Mr. F. Lewis has patented a device by which a squirrel-cage motor may be made so as to give a large starting torque without the addition of external resistance. Its action depends on the fact that a wound rotor, unlike the squirrel-cage, will only work in a rotating field having the number of poles for which the winding is designed. His rotor has two windings. In the bottom of the slots there is a "wound" set of coils of low resistance permanently connected up and short-circuited on itself. On the top of this there is a squirrel-cage winding of a high resistance. To start the motor the field is arranged so as not to give the required polarity for the wound set of coils, and hence it remains inactive. The squirrel-cage winding, however, comes into action, and starts the motor with a large torque, its high resistance preventing a

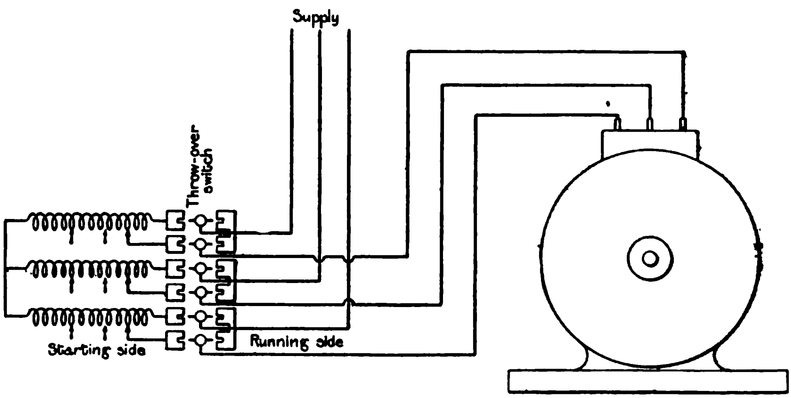

FIG. 5.

large current. When the motor speeds up the proper polarity for the other winding is brought into action, and it then drives the motor. Of course, the squirrel-cage winding continues to do a small part of the driving, but the low-resistance winding does the bulk of the work.

One application for which the squirrel-cage motor is particularly well adapted is coal mine working. The entire absence of slip-rings and brushes reduces the danger from sparking to a minimum, and besides, the fact that there is no intricate mechanism to get out of order renders it very suitable to be worked by unskilled persons and subjected to the rough usage which material is usually subjected to in pits. These reasons, combined with the economy in copper in the transmission lines, have led to a large use of induction motors in colliery working.

(2) Wound rotors have been made and used without collector-rings, but this arrangement is not very efficient. The usual way to start these

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motors is to have an external resistance in each rotor phase when starting, the resistance being gradually cut out as the rotor runs up to its speed. The connections are shown diagrammatically in Fig. 6. When the motor is running up to its speed the ends of the rotor windings are short-circuited by means of an internal mechanical arrangement represented at S, and the brushes may then be raised from the slip-rings.

Difficulty of obtaining variable speed is one of the chief objections to the use of induction motors. There are, however, several methods of obtaining a variable speed, although they are more or less unsatisfactory. One method is to put a resistance permanently in series with the rotor windings. The action of this has been already explained.

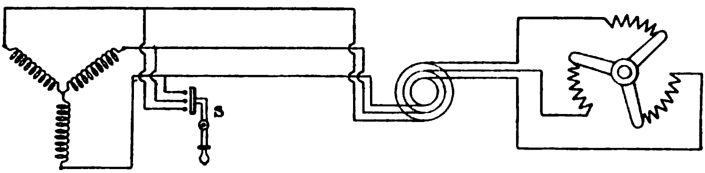

FIG. 6.

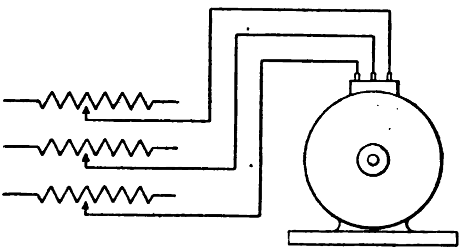

FIG. 7.

Of course, since the resistance is to be permanently in circuit, the rheostat will require to be large and expensive. The more resistance there is in circuit the lower will be the speed, but also the lower will be the efficiency. The speed, of course, for each step, will vary with the load on the motor as usual. Wound rotors are better adapted for this type of speed regulation than squirrel-cage rotors, but the method is uneconomical, and is analogous to putting a resistance in series with a direct-current armature.

Another method is by means of potential control. This consists in putting resistances or inductive resistances in series with the stator coils, and so lowering the potential at the terminals of the motor. By this method the use of slip-rings may be avoided if the motor may start at no load. The connections are shown in Fig. 7. The method is less efficient than the rheostatic control previously mentioned.

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Since the speed of an induction motor depends upon the number of stator poles, it is obvious that it may be varied by varying the number of poles on the stator. This requires special arrangements, and at the same time the winding on the rotor, if it is a wound one, will require to be adjusted to suit each new number of poles. In cases where this method is to be used squirrel-cage rotors are therefore the more suitable, as they accommodate themselves to the number of poles in the stator winding without any trouble. It will be seen that by this method there will be only a few definite speeds, one corresponding to each number of poles used.

However, the fact that an induction motor will run approximately only at one fixed speed is of great service in several classes of work where constancy of speed is a necessity. Especially is this the case in the working of weaving machinery, and particularly in the silk-weaving industry. In ordinary textile factories a constant speed of driving is desirable, but in these cases a number of machines may be driven from one line of shafting. In the case of silk weaving it is best, however, to have a separate motor for each machine, in order to avoid damage to material by overhead oil, dirt, etc. These motors are made of the 3-phase squirrel-cage type, and the full load speed they usually run at is 1,000 revs. per minute. The kind of arrangement used is to pivot the motor at one side and suspend it from a spring on the other. This allows the motor to start on a fairly light load, as the belt will at the start merely slip round the pulley.

High Speeds and Low Frequencies.—In the design of induction motors two points of great importance are the use of high speeds and the use of low frequencies. The speed, of course, depends on the number of poles, but windings having different numbers of poles are not all equally suitable for induction motors. For instance, 2-pole windings are not so suitable for induction motors as 4-pole or 6-pole windings, since the speed of the rotor would be very great unless the frequency was very low. Hence a 4-pole winding will be used instead of a 2-pole one if it is at all practicable. However, for reasons which have been already pointed out, the number of poles in small machines will be restricted. It is desirable to have the distance between the poles as great as possible, in order to increase the length of the path of the leakage lines and so reduce the leakage flux, that is, the flux which is not linked with the rotor winding but merely passes through the stator windings.

Since the revs. per minute $= n_r$

$$= \frac{(1 - S) \sim}{P},$$

$$\therefore P = \frac{(1 - S) \sim}{n_r},$$

it means that if the length between the poles is to be as great as possible, that is, if the number of poles is to be as small as possible, a

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low frequency is required or a high speed or both. If the motor must be run at a low speed, then it is necessary that the frequency should be low. If the frequency of supply is high, then it is necessary that

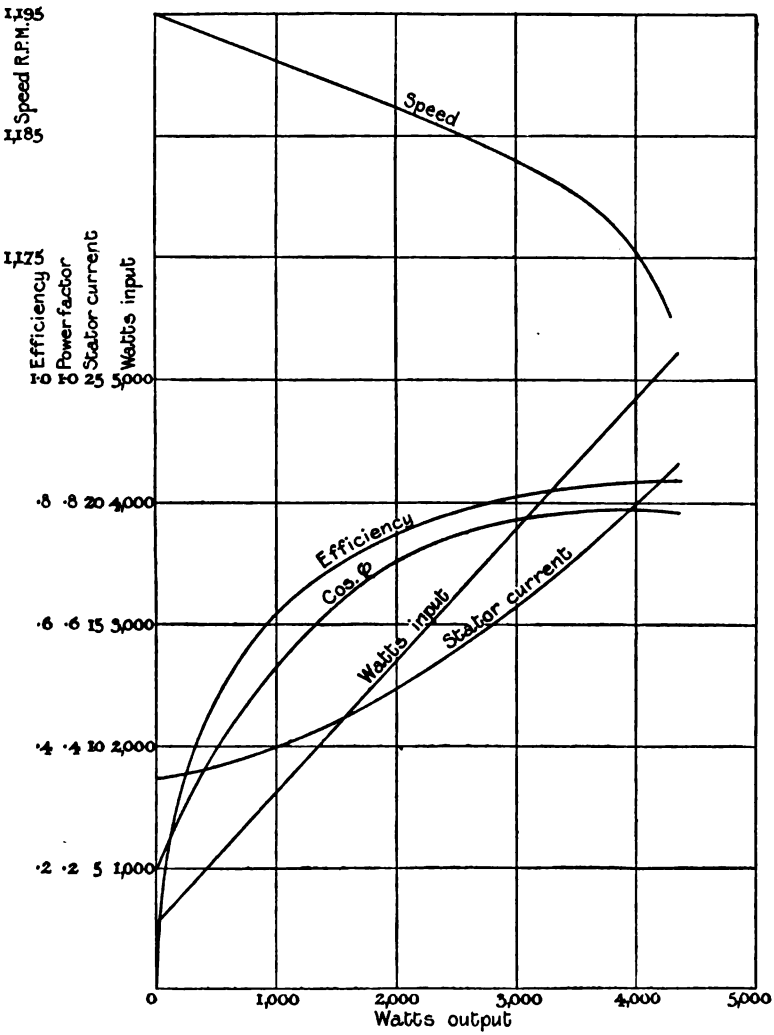

FIG. 8.

the speed should be as high as possible. This is a point the importance of which is overlooked by a great many people; some designers even have not a proper notion of its importance.

The chief point to be borne in mind, then, in designing an induction

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motor is that the leakage should be kept down. A large leakage means a low starting torque and a low power factor at all loads. To keep down the magnetic leakage the pole pitch should be as great as possible, implying, as has been already said, a low frequency or a high speed; the slots should be shallow and the teeth narrow, so as to allow of a high working flux density, and the air-gap should be made as short as mechanical considerations will allow.

The set of curves shown in Figs. 8, 9, and 10 were obtained from a motor of the wound rotor type made by the Electrical Company, London. These curves show the results to be expected from any reasonably well designed motor. The friction loss may be obtained from the magnetisation curve or by plotting a retardation curve.

In the first method the voltage at the terminals of the motor is varied, starting from a low value. The watts taken at various voltages are plotted with the volts as abscissæ. The intercept of the watts curve on the axis of ordinates gives the watts loss when the voltage is zero, that is, the watts loss due to friction.

In the retardation method the motor is run up to full speed and then the supply is cut off. Readings of the speed as it falls are taken at intervals and plotted on a time base. The friction loss is found as follows:—

Let angular velocity of rotor $= \omega$.

Total couple $= I\dot{\omega}$, where $I =$ moment of inertia of rotor about centre line in C.G.S. units.

Work done $= I\dot{\omega} \times 2\pi n$.

$$= 4\pi^2 I \left(n\frac{dn}{dt}\right) = \text{friction loss},$$

when $n =$ revs. per second.

The expression in brackets is the sub-normal of the speed-time curve. Hence by finding I and $\frac{dn}{dt}$ at any point, the friction loss may be determined for that speed represented by the point on the curve.

The accompanying magnetisation and retardation curves (Figs. 9 and 10) were obtained from another motor by the Electrical Company, London. The watts absorbed and the speed are plotted on a volts base. The synchronous speed of the motor was 1,000 revs. per minute. Taking 960 revs. per minute as the normal running speed, drop a perpendicular through the point corresponding to that speed on to the axis of abscissæ and cutting the watts curve. Produce the watts curve from the point where the perpendicular cuts it back to the axis of ordinates. The intercept represents the watts lost in friction. In this case it is found to be about 342 watts. For more accurate work the C^2R loss in the rotor should be deducted from the watts absorbed.

By plotting the speed-time curve on a larger scale, $n\frac{dn}{dt}$ for 960 revs. per minute is found to be 2·88.

By bifilar suspension the moment of inertia of the rotor was found

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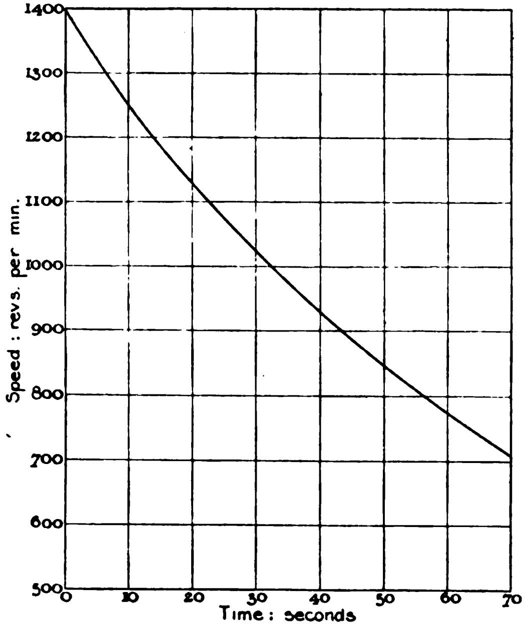

FIG. 9.

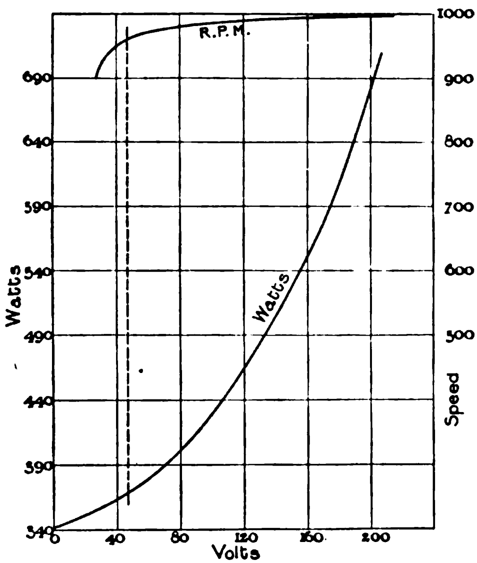

FIG. 10.

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to be 2·89 kilogramme-metres. Hence from the previously found formula the friction loss thus found is 333 watts.

A difference of 3 per cent. exists between these values.

By calculating $n\frac{dn}{dt}$ for various speeds a curve may be plotted giving friction loss at various speeds of the motor.

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THE EQUIPMENT OF STEAM TURBINE GENERATING STATIONS.

By R. J. KAULA.

(*Abstract of Paper read before the Students' Section, London, December* 5, 1906.)

The properties of steam, as indicated in the entropy diagram, apply equally to turbines and reciprocating engines, so that a theoretical gain will be obtained in both cases by raising the working pressure. In the case of the Parsons turbine, however, this gain is more limited, owing to practical considerations, than is the case in the older form of engine. It has been found that the high-pressure stages are the least economical, owing to the shortness of the blades and the consequently large ratio of clearance to blade length. Taking into account the relative cost of boilers, a steam pressure of 150 lbs. will mostly be found sufficiently high in the case of steam turbines, whereas a considerably higher pressure would undoubtedly prove more economical with suitably designed reciprocating engines.

The gain obtained by superheating steam for reciprocating engines is generally accounted for by the reduction in cylinder condensation.

In the case of steam turbines the resulting gain is rather of a mechanical nature, namely, owing to the lower friction coefficient of superheated as compared with saturated or wet steam. The chief objection to the use of superheated steam in reciprocating engines, viz., the increased difficulty of cylinder lubrication, disappears entirely in the case of steam turbines, and a superheat of 200–220° F. above saturation may be considered a safe and economical figure as a general rule. Fig. 1 shows the effect of superheat on the steam consumption for a 3,000-k.w. steam turbine of the Brown-Boveri Parsons type.

Boiler House.—It is generally conceded that the best possible, in fact an ideal, arrangement is secured by placing the boilers in single or double lines along the engine-room, so that each boiler or battery of boilers supplies steam to a generating set immediately behind it, thus forming individual units. In most stations equipped with reciprocating engines it has been found possible to work in this arrangement, and the same applies to small turbo-generators. But the improvement gained in engine-room space efficiency by the introduction of large turbo sets was not followed immediately by a similar improvement in the case of the boilers. As a consequence, the housing of the steam generators involved considerable difficulties, and it is of interest to compare the various methods adopted in practice to cope with the question.

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In the United States and in English stations built on American lines, double-deck boiler houses have occasionally been resorted to; Lot's Road Station, Chelsea, may be cited as a typical example. The disadvantages of this system are pretty obvious.

At the Carville Station of the Newcastle Electric Supply Company, the boiler houses are placed at right angles to the engine-room, involving comparatively long pipe lines.

At Yoker and Neasden the turbo-generators are placed end to end alongside the boiler house. This arrangement sacrifices the convenience of the engine-room to that of the boiler house, as it increases the work of attendance and complicates the pipe lines.

Vertical boilers, such as the "Climax" boilers installed at Grove Road, have an excellent floor space efficiency, but the difficulties of cleaning and stoking have prevented this type from coming into more general use.

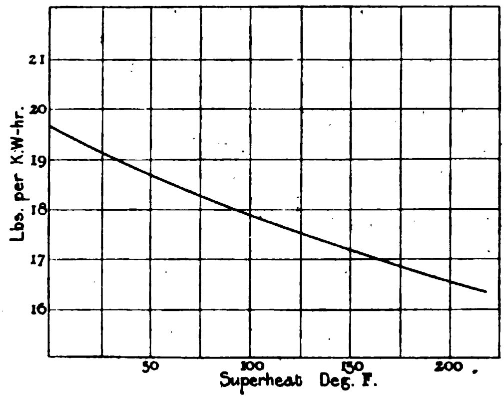

FIG. 1.

Fig. 2 shows the floor space efficiency of Nesdrum water-tube boilers as a function of the capacity. This is based on hand-fired coal having a thermal value of 12,500–13,000 B.T.U. and on normal natural draught. In view of the tendency to use "waste gases" for firing boilers for electrical purposes, it is of interest to note that this curve would hold good for blast-furnace gas, but the space efficiency must be somewhat reduced for coke-oven gas. To work through a concrete example, the author has chosen a boiler house containing four batteries, each consisting of two boilers with a capacity of 20,000 lbs. each (Fig. 3).

The overall width of the boilers is 91 ft., and this would allow space for four 3,000-k.w. turbo-generators. But taking the steam consumption at 16 lbs. per k.w.-hour, or 48,000 lbs. per set, the output of the boilers is too low for the purpose. By introducing under-feed stokers with fan-draught in place of hand-firing, the boiler capacity will be increased by 15–20 per cent., and a further improvement of, say, 10–15 per cent. will be obtained if economisers are introduced.

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The capacity is thus 50,000 to 55,000 lbs. per battery per hour, so that there is an ample margin on the normal load of the turbines. The rating of the boilers is sufficiently low to enable them to deal with an overload of 4,000 k.w. for periods of, say, two to three hours.

To obtain the necessary draught, two 100-in. fans would be required, a third fan being provided as a standby. In the figure, one fan is placed at either end of the boiler house, so as to give an even air pressure, the standby being also placed at the far end. Air ducts are built under the floor, with branches on either side. The fans would be driven by 36-H.P. motors running at a speed of 580 r.p.m.

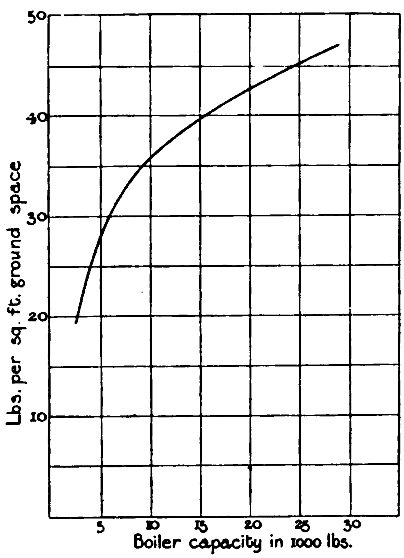

FIG. 2.

The economisers would be of the high-pressure type, capable of raising the temperature of the feed from about 80° F. to about 260° F. For a large installation, such as the present one, the economiser plant might be arranged in four batteries similarly to the boiler plant. Behind each row of boilers two flues are shown. The upper flue contains the economisers, and the hot gases enter the lower flue and are led into the economisers at the far end, namely, the end farthest from the chimney. The lower flue further serves as a reserve in case the economisers require to be overhauled, suitable dampers being provided to allow the gases to pass straight to the chimney, and at the same time shutting off the economiser flue.

The floor of the boiler house may well be on a level with the condenser pit floor. In the present example space is allowed for a doorway opposite to the passage between the two rows of boilers,

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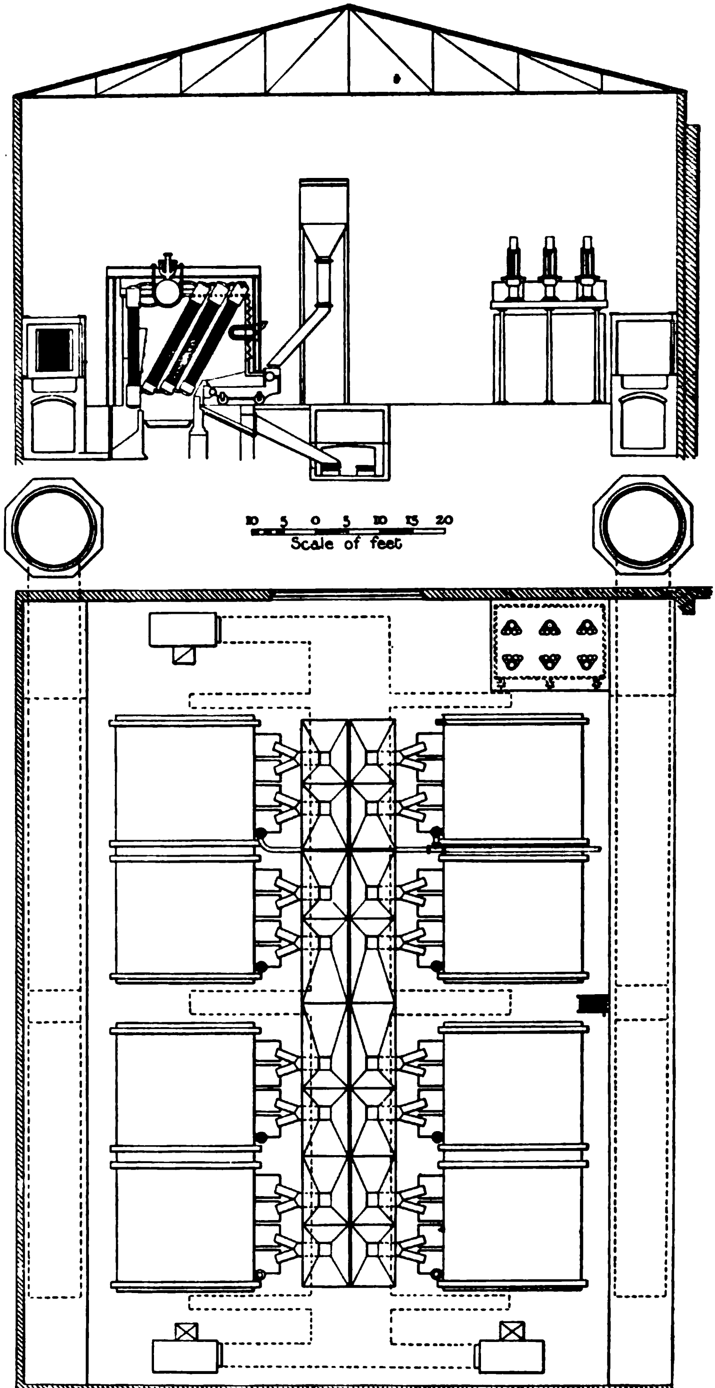

FIG. 3.

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which is 28 ft. in width. This passage must be calculated to allow the stokers to be dismantled without interfering with the opposite boiler. At one side of the doorway a hot-well tank has been placed with a capacity of 18,000 gallons, equal to the hourly capacity of four boilers. The feed pumps shown are of the reciprocating steam-driven type, and are placed on a gallery above the hot-well tank. Each pump would be capable of feeding one battery of boilers, and two pumps would be provided as standby. Single-stage turbine-driven feed pumps of the De Laval type, built by Messrs. Greenwood & Batley, are now in use at Carville, running at a speed of 13,000 r.p.m.

Provision would also be made for a coal conveyor. This can also be used for removing the ashes, otherwise these can be carried away in bogies running along the floor.

A few approximate figures may be of interest.

The boilers themselves might be estimated at £12,000, or 20s. per k.w., and the superheaters would involve an additional cost of, say, £2,700, or 4s. 6d. per k.w. The cost of the complete economisers would be about £4,500, or 7s. 6d. per k.w.

Assuming coal at 10s. per ton having a calorific value of 13,000 B.T.U., further taking the load factor at 20 per cent., the average hourly total steam consumption* would be $12{,}000 \times 16 \times \frac{20}{100} = 38{,}400$ lbs. The coal consumption is given by the equation—

$$H = \frac{Q \times \lambda}{C \times \eta} = \frac{38{,}400 \times 1{,}265 \times 100}{13{,}000 \times 65} = 5{,}760 \text{ lbs.},$$

where

H = Weight of coal burnt per hour in lbs.

Q = Hourly steam consumption in lbs.

λ = Heat units above feed water temperature contained in 1 lb. of steam = 1,265 B.T.U. for 80° feed water, 150 lbs. steam pressure, and 200° F. superheat, assuming the specific heat for superheated steam = 0·6.

η = Efficiency of boiler exclusive of economiser, taken as 65 per cent. as a minimum.

Hence the annual coal bill will be—

$$\frac{£5{,}760 \times 365 \times 24 \times 0{\cdot}5}{2{,}240} = £11{,}250.$$

The use of economisers will improve the efficiency by at least 10 per cent., and will therefore reduce the coal bill by £1,125, equivalent to a return of 34 per cent. on the capital involved. With due allowance for depreciation, power consumed by the scrapers, and cost of attendance, this figure amply demonstrates the financial advantage of installing economisers.

The boilers which have been considered approach the limits in

* The average steam consumption must be higher than the full load steam consumption, so that the actual total steam consumption will be higher than the value given.

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size, as far as convenience of handling is concerned. It is therefore hardly feasible to obtain any further improvement in space efficiency by increasing the dimensions. But within the last few years boiler makers have adopted their marine type for use in central stations, thus gaining a further advantage though at a somewhat increased cost.

The author is indebted to Mr. L. Taylor, of Messrs. Richardsons, Westgarth & Co., Middlesbrough, for some interesting figures in this connection. These are given in Table I., and it should be mentioned that they do not include the saving which would be obtained by the use of economisers.

TABLE I.

Type of Boiler.	Batteries of Two Boilers. Evaporation in lbs. per Hour from and at 212° F.	Ground Space Occupied.*	Stoker.
Babcock & Wilcox marine type arranged for land service	56,000	39 ft. × 26 ft.	Chain grate stoker
Stirling marine type arranged for land service	60,000	39 ft. × 26 ft.	Chain grate stoker
Nesdrum "Bow" type	64,000	39 ft. × 23 ft.	Erith's underfeed stokers.

* Ground space includes space occupied by stokers.

It will be noted that these figures represent an improvement of about 50 per cent. on the figures given for the same ground space in Fig. 2.

Engine House.—The cost of the steam-pipe work and valves amounts to about 4s. to 6s. per k.w. The losses are due to friction of the steam passing through the pipes; and, secondly, to radiation, resulting in a reduction in superheat, or in condensation in the case of saturated steam. The former loss naturally increases with a reduction in the diameter of the pipe, but the radiation loss decreases at the same time. The friction loss, whilst reducing the pressure, increases the superheat, and is therefore not so wasteful as the radiation loss. As previously mentioned, a loss of steam pressure would not affect the economy of a steam turbine to the same extent as it would that of a reciprocating engine, so that it would appear reasonable to allow a comparatively greater drop in pressure in the case of turbines, thereby maintaining the superheat as far as possible, and at the same time reducing the first cost. Notwithstanding the somewhat

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different conditions, the losses are of about the same order for superheated as with saturated steam.*

It is advisable to interconnect the various units, so as to make the individual turbines independent of their respective batteries of boilers. In the pipe line shown in Fig. 4 stop-valves are placed in the connecting pipes, which would be kept closed under normal working conditions. Although the amount of water is usually very small, a steam separator should be placed before the turbine stop-valve, especially as the turbine may occasionally be required to work with saturated steam.

In the case of turbo-alternators, the curious fact appears that for every given frequency there are certain outputs which are uneconomical both as regards first cost and steam consumption, and they should therefore be avoided. It is further apparent that the most favourable outputs are such as represent maxima of their respective speeds.

The previous example may serve to illustrate this point. We are dealing with polyphase alternators having an assumed total output of 12,000 k.w. and a frequency of 50 $\sim$, with an overload capacity of 25–30 per cent. for two to three hours. If all sets are to have a uniform output, there might be three at 4,000 k.w., four at 3,000 k.w., or a greater number having a proportionately reduced output.

Practically all manufacturers are prepared to build 3,000-k.w. units at a speed of 1,500 r.p.m., but at the present moment this speed would be considered excessive for 4,000-k.w. sets, and these would therefore require to run at 1,000 r.p.m. As a result, the respective full load steam consumptions will be approximately equal in either case, so that the balance would be in favour of the smaller sets for practically all outputs. Furthermore, the cost per k.w. will be greater in the case of the larger units. Another important feature in favour of the smaller sets is the reduced percentage of plant required to be installed as standby. By decreasing the output below 3,000 k.w. the capital expenditure would again increase, and the same applies to the steam consumption, for the only higher speed possible, viz., 3,000 r.p.m., is prohibitive for all but comparatively small units.

It should not be implied that a station consisting of a number of identical units is always desirable. If the station consisted of three 3,000-k.w. and two 1,500-k.w. sets, interchangeability would be maintained to a great extent, and the whole system would gain in flexibility. The full load steam consumption of a 1,500-k.w. set would be about 5 per cent. higher than that of the larger machine, but with both machines giving an output of 1,500 k.w., the smaller machine would consume 10–12 per cent. less steam. In the case of future extensions, a fourth 3,000-k.w. unit might be installed, this to be followed by 6,000-k.w. sets. The cost of polyphase turbo-alternators varies considerably, from about £3 to £5 per k.w., according to the output. The cost of single-phase sets may be taken as 10–15 per cent. above

* Berner, *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 48, p. 473, 1904.

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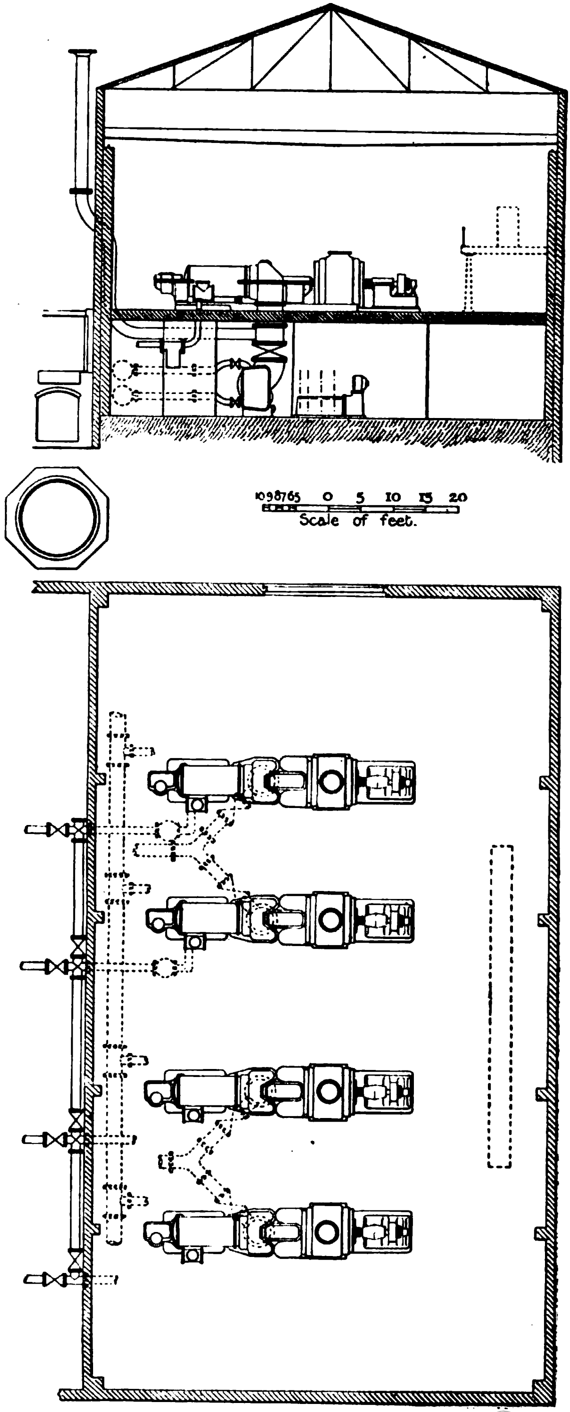

FIG. 4.

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these figures, and the cost of continuous-current turbo-generators would be about 20 per cent. higher.

A crane is most necessary when the initial plant is being erected, and it would therefore probably pay to install a hand-crane in the first instance, and to exchange the crab as soon as the first set is got under way, so that current is available for electric driving. This would hardly be necessary in a station provided with separately driven exciting sets which also supply current to the auxiliaries.

The switchboard may be placed either at right angles or parallel to the generating sets. The latter arrangement is preferable as regards space efficiency, and gives the attendant a better view of the prime movers. The former position allows more space for extensions. In modern stations telegraphic signalling arrangements are provided between the switchboard gallery and the various units.

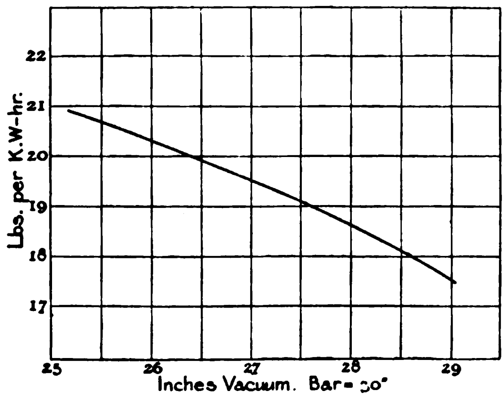

FIG. 5.

Condenser Pit.—A Parsons turbine exhausting into a vacuum of 26 ins. to 28 ins. is capable of giving an output of 30 per cent. to 50 per cent. above that of a non-condensing turbine of equal weight and cost. Fig. 5 shows the reduction in steam consumption, with varying vacuum, for a 1,000-k.w. Richardsons' Brown-Boveri turbine. In all cases the barometric pressure is assumed to be 30 ins. of mercury.

For average conditions the vacua given in Table II. for various temperatures of cooling water should be allowed for on full load. Where the turbo-generators are required to work on overload for long periods, the vacua given should be obtained on this overload.

There is a certain limit beyond which the vacuum must not be pushed on any account, namely, when the whole or a large proportion of the saving in steam consumption is consumed by the additional power required by the pumps.

Such a case might easily arise if it were proposed to raise the

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vacuum from 27 ins. to 28 ins. where the circulating water is cooled in natural draught towers.

TABLE II.

Temperature of Cooling Water.	Suggested Vacuum with the Barometer at 30 ins.
75°–85° F.	26 ins.–27 ins.
65°–75° F.	27 ins.–28 ins.
Under 65° F.	28 ins.–28½ ins. or higher.

The average temperature of the water at the bottom of the tower would be 80°–85° F., and the head would be about 50 ft., made up in the manner shown in Table III., where the circulating pump is assumed to be on the condenser pit floor level.

TABLE III.

	Feet.
Cooling Tower Water Lift	25
Height of Condenser Pit	15
Head Due to Condenser and Pipe Friction	20
Drop from Cooling Tower Tank to Pump	12
Total Head...	48

If the outlet temperature of the cooling water approaches within 7° F. of the vacuum temperature, a maximum temperature difference of $116 - 7 - 80 = 29°$ F. will be available at 27 ins. vacuum, and this will be reduced to $101{\cdot}5 - 7 - 80 = 13{\cdot}5°$ F. at 28 ins. vacuum. The quantity of circulating water required will therefore be $\frac{1{,}035}{29} = 35$ times the feed and $\frac{1{,}040}{13{\cdot}5} = 77$ times the feed respectively.*

Taking the case of a 500-k.w. turbo-generator consuming 20 lbs. per k.w.-hour, the additional power required by the circulating pump will be $\frac{500 \times 20 \times 42}{33{,}000} = 12{\cdot}7$ water horse-power, corresponding to a power consumption of about 16 k.w. Adding to this, say, 2 to 3 k.w. on account of the air-pump, it will be seen that 65 per cent. to 75 per cent. of the gain in steam consumption, namely, 5 to 6 per cent., is consumed by the pumps. The result would be still less favourable at lighter loads, owing to the reduced efficiency of both circulating pump and motor.

The capital cost of jet condensing is, in most cases, considerably

* The above method of finding the ratio of circulating water to feed, namely, temperature difference divided into latent heat of steam, neglects the pressure of water in the exhaust, thereby erring on the safe side.

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lower than that of a surface condensing plant, and the quantity of cooling water required, especially at high inlet temperature, should be somewhat less. To offset these advantages, the condensed steam cannot be used as feed water unless the cooling water is quite pure. The cost of fresh water would in many cases more than compensate for the saving in capital outlay, and to this cost must be added the heat units consumed in raising the temperature of the fresh water to that of the condensed steam. Jet condensers are now commonly made of the barometric counter-current type working in connection with dry air pumps.

With a surface condenser the outlet temperature of the circulating water should approach the temperature corresponding to the vacuum as closely as possible, so as to keep down the quantity of cooling water required; and the area of the cooling surface should be a minimum, so as to reduce the weight and cost of raw material and at the same time improve the space efficiency of the condenser. To attain both objects the heat transmission coefficient of the cooling surface must be a maximum to allow the cooling water to reach a high temperature whilst passing through the condenser at a high rate of flow. There is a slight improvement in the heat transmission coefficient with increased speed of the water, but this is not sufficient to compensate for the shorter time during which the water remains in contact with the tubes.

The design of the well-known "Contraflo" condenser is based mainly on these considerations, and is therefore especially adapted for the class of work under consideration.

There are three distinct forms of air pumps commonly used in connection with condensing plant. Firstly, the wet air pump, known in its most usual form as the Edwards pump. The great advantage of this type is the simplicity of the construction and the absence of foot and bucket valves. The hot-well water and air are removed together, the water being used for sealing purposes and for taking up the clearance.

With the second type of pump, the so-called "dry" Edwards air pump, the whole or greater part of the hot-well water is removed straight from the condenser to the feed tank by means of the force pump without coming into further contact with the air and vapour. The sealing water is either supplied by a small portion of the condensed steam, which would be cooled down as far as possible, or by means of a cold-water spray introduced into the pipe-connection between condenser and pump.

The third type is the dry air pump proper, in which no water is used for sealing the valves and taking up the clearance, this type being commonly used in connection with jet condensers. These pumps should preferably be double acting, and any form of mechanically operated valves may be employed.

A circulating pump will be required, except there be sufficient head on the water to overcome pipe-line and condenser friction. It is

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customary to provide a syphon action on the circulating water line if this is at all feasible, as a saving of 25–30 ft. of the head can thereby be obtained.

The author will now consider the details of a suitable condensing plant for the 3,000-k.w. turbo-generators referred to above. In arranging the position of the condenser space must be allowed for drawing the tubes. To avoid a downward pull on the turbine cylinder, provision must be made to take up the vertical expansion of the condenser shell and connecting pieces. A satisfactory means of providing the necessary elasticity is to fix a bellows pipe or expansion piece immediately below the turbine exhaust flange. Some manufacturers place the condenser on spring foundations for this purpose. The diameter of the exhaust flange is 60 ins., and a sluice valve of this size would cost about £200. By omitting this valve the depth of the condenser pit is also reduced, but it is then impossible to exhaust into the atmosphere for any length of time. To handle a valve of the above size conveniently, it is advisable to drive the spindle by means of a small motor with a high starting torque. An automatic atmospheric relief valve is absolutely essential, as in case of a stoppage occurring on the air pump or circulating pump the pressure in the condenser would rapidly rise and would probably fracture the condenser shell

The condenser is of the "Contraflo" type, having a cooling surface of 3,500 sq. ft. The air pump is a three-throw dry Edwards pump, having barrels 19 ins. diameter by 15 ins. stroke, with direct driven force pump and a cold-water spray. This pump runs at a speed of 115 r.p.m. and is driven by a 25-H.P. motor by means of a 5 : 1 gear. The condensing plant is capable of maintaining a vacuum of 28 ins. when dealing with 48,000 lbs. of steam per hour, the full load steam consumption of the 3,000-k.w. turbine. The condenser requires 2,700 gallons of circulating water per minute at a temperature of 65° F.

If the circulating water is drawn from a river or canal at some distance from the station, it is best to build a pump house close to the source of supply, to reduce the suction head as far as possible. The total quantity of water to be dealt with in the example is 10,800 gallons per minute, but it is not to be assumed that more than three out of the four units would be working simultaneously, so that about 8,000 gallons per minute would be the greatest quantity to be supplied at any time.

A suitable pump house might contain three motor-driven centrifugal pumps, each capable of delivering 4,000 gallons per minute at a speed of 750 r.p.m., one set acting as a standby. Assuming the total head at 30 ft. and a pump efficiency of 75 per cent., the motor would have an output of about 50 H.P. Each pump should have a separate suction pipe and discharge into a common delivery main leading to the condenser pit. The pump house should be designed to accommodate two further sets as extensions.

In the case of small turbo-generators it may be more economical to install central condensing plant in preference to independent condensers. A considerable reduction in capital outlay will thereby

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be obtained, but where a high vacuum is required not more than two turbines should exhaust into the same condenser, owing to the increased risk of air leakage due to the multiplication of joints. With increased dimensions of the plant the saving decreases and the exhaust pipes become unwieldy, so that 400 to 500 k.w. sets may be taken as the limit for central condensers. A great advantage of this arrangement is the fact that the vacuum can be raised when one set only is working. The chief drawback is the necessity to work both sets non-condensing whenever the condenser tubes require to be cleaned.

In conclusion, the author wishes to express his thanks to Mr. D. B. Morison, Managing Director of Messrs. Richardsons, Westgarth & Co., Hartlepool, for his permission to bring this paper before the students of the Institution, and he is greatly indebted to Mr. A. V. Davies for his kind assistance in preparing the drawings.

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Proceedings of the Thirty-fifth Annual General Meeting of the Institution of Electrical Engineers, held in the Library of the Institution, 92, Victoria Street, Westminster, London, S.W., on Friday afternoon, May 24, 1907—Dr. R. T. GLAZEBROOK, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on Thursday, May 23rd, were taken as read and confirmed.

The names of new candidates for election into the Institution, after having been suspended previous to the meeting in the Library, were taken as read, and the President stated that the present meeting being the last of the Session, the candidates would as usual be balloted for that evening.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members :—

Robert L. Acland.
Peter Albertine.
V. A. Mundella.
Wm. Thos. Taylor.
B. Welbourne.

From the class of Associates to that of Associate Members :—

Wm. P. Miller.

From the class of Students to that of Associate Members :—

Ralph Hardy.
A. M. Johnson.
Lucien A. Lewis.
Henry F. Vickery.

Messrs. L. Gaster and W. M. Madden were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected

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ELECTIONS.

As Associate Members.

Ernest J. Aldworth.
Horace W. Angus.
James E. Brown.
Benjamin Davies.
Charles T. Eriksson.
Geo. M. Henderson.
Harry V. Kilburn.
Percy Watson.

As Students.

J. A. Manners-Smith.
Arthur V. Newman.
Arthur C. Rayment.
Albert Smith.

The Report of Council was then presented as follows :—

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REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF MAY 24, 1907.

At this, the thirty-fifth Annual General Meeting of the Institution of Electrical Engineers, the Council are pleased to present to the members their Report upon the proceedings and work of the Institution during the Session 1906–7.

GROWTH OF THE INSTITUTION.

Since the date of the last Annual General Meeting, 203 proposals for election to corporate membership, and 292 proposals for election as Student have been considered, and there have been elected 15 Members, 163 Associate Members, 9 Associates, and 289 Students. The names of 1 Member, 3 Associate Members, and 5 Associates have been restored to the register, the total addition to the Roll being 485, against which there is to be set the decrease owing to deaths, resignations, and erasures from the List.

To the class of Members there have been transferred 40 Associate Members and 11 Associates, and to the class of Associate Members there have been transferred 63 Associates and 48 Students.

The change in the Roll during the past twelve months is shown in the following table :—

	1906.	1907.
Honorary Members	6	7
Members	1,012	1,055
Associate Members	1,805	1,981
Associates	1,419	1,269
Students	1,436	1,517
Foreign Members	125	116
Total	5,803	5,945

At the end of the last Session the question of adopting a more stringent procedure in dealing with applications for election and transfer was under consideration by the Council; and with a view to the strict enforcement of the rule that the proposer and seconder, at least, should have a personal knowledge of candidates recommended

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by them for election or transfer, it was thought expedient that they should be in confidential communication with the Council. The plan has therefore been adopted of sending out, on receipt of every application for election or transfer, a form of confidential inquiry to the proposer, seconder, and one supporter (and to others if all replies are not satisfactory), requesting them to state the extent of their personal knowledge and to express their opinion as to the candidate's fitness for admission to the Institution. The confidential replies are submitted to the Council at the time the respective applications are brought forward for consideration. By this means the Council have received valuable assistance from the members in upholding the interests of the Institution and of all belonging thereto. Every application for election or transfer which may have been approved in Council meeting is regarded as provisionally approved, and is deferred for confirmation or otherwise of such approval at a succeeding meeting.

The Council note with pleasure that honours have been conferred upon several of the members during the past year. In 1906 Sir H. B. Jackson, K.C.V.O., R.N., F.R.S., Member, had bestowed upon him the Order of Knight Commander of the Victorian Order; Mr. John Ardron, C.B., Associate, received the Order of Companion of the Bath; and Mr. A. J. Walter, K.C., past Associate Member of Council, was appointed King's Counsel. Mrs. Hertha Ayrton, Member, was awarded the Hughes Medal of the Royal Society, in recognition of the value of the research work carried out by her.

Election of Honorary Member.

In conformity with Articles 11 and 17 of the Articles of Association the Council have this year elected as Honorary Member of the Institution Professor Joseph John Thomson, D.Sc., F.R.S., Cavendish Professor of Experimental Physics at Cambridge and Professor of Physics at the Royal Institution. It will be remembered that early in the year the Institution was favoured in hearing from Professor Thomson a brilliant address on the subject of "The Modern Theory of the Conductivity of Metals."

Members Deceased.

Heavy loss has been suffered by the Institution during the past year by the decease of several well-known members. Among these the Council have had to record with deep regret the names of Sir Benjamin Baker, K.C.B., K.C.M.G., Mr. I. A. Timmis and Mr. L. Loeffler, Members, and Mr. E. Hospitalier, Foreign Member.

The full list of members deceased is as follows :—

Members.

Sir Benjamin Baker, K.C.B., K.C.M.G.
J. R. Brittle.
W. A. Bryson.
F. T. Hollins.
S. Joyce.
J. W. Leyshon.
L. Loeffler.
I. A. Timmis.

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Associate Members.

W. R. T. Cottrell.	J. Maclean.
E. A. Ellicott.	R. S. B. Pyne.
D. B. Ingram.	C. N. Sims.

Associates.

L. Cassier.	E. Earle.
E. C. R. Deefholts.	W. J. Greer.

Foreign Members.

F. L. Freeman.	E. Hospitalier.	J. Tatham.

Resignations.

4 Members, 10 Associate Members, 35 Associates, 6 Foreign Members, and 55 Students have resigned since the date of the last Report.

Procedure in Nominating Candidates for Election to the Council.

Attention has been directed to the desirability of facilitating action by the members, should they desire to nominate any candidate or candidates for election to the Council in addition to those nominated by the Council to fill the vacancies at the end of each Session. In accordance with Article 45 of the Articles of Association, the Council has to present, at an Ordinary General Meeting held not later than twenty-eight days before the Annual General Meeting, a list of candidates sufficient to fill vacancies caused by retirement of Members of Council in rotation each year. Any Member may make further nominations, provided these are sent in to the Secretary in writing within seven days after the Ordinary General Meeting at which the Council nominees are announced, and such additional candidates must be proposed and seconded by two Members and supported by eight other Members. As, however, the statutory period of seven days affords scarcely sufficient time for Members, after learning the names of the Council nominees, to obtain the consent of any other Member to accept nomination for election, and to complete the requisite formalities, the Council have decided that in future years the list of names of their nominees shall be circulated to all members of the Institution, together with the notice of, and at least a week in advance of, the Ordinary General Meeting at which the announcement is made by the Council. By this means the members will receive full notice of the action of the Council a fortnight before the expiration of the time within which further nominations, necessitating a ballot, can be presented.

Meetings and Papers.

During the past Session 18 General Meetings and 21 Council Meetings have been held. Nineteen Committees have been at work under the Council, the total number of Committee Meetings held being 102. The number of papers read before General Meetings has been slightly in excess of the average, and subjects of great importance and interest to the profession have been dealt with and discussed. At the opening

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Meeting of the Session on November 8th the President delivered his Inaugural Address to the Members, and at the subsequent Meetings the following papers were read :–

1906.
Nov. 22.—"Testing of Electric Machinery and of Materials for its Construction," by Professor J. EPSTEIN, Foreign Member.
Dec. 20.—"The Track Circuit as Installed on Steam Railways," by H G. BROWN. Associate Member.
1907.
Jan. 10.—"New Incandescent Lamps," by J. SWINBURNE, F.R.S., Past-President.
" 24.—"Investigations on Light Standards and the Present Condition of the High-Voltage Glow Lamp," by C. C. PATERSON, Associate Member.
Feb. 7.—"Comparative Life Tests on Carbon, Nernst, and Tantalum Incandescent Lamps using Alternating Currents," by H F. HAWORTH, T. H. MATTHEWMAN, and D. H. OGLEY.
" 21.—"The Modern Theory of Electrical Conductivity of Metals," by Professor J. J. THOMSON, F.R.S., Honorary Member.
Mar. 7.—"The Transmission of Electrical Energy by Direct Current on the Series System," by J. S. HIGHFIELD, Member of Council.
" 21.—"Rail Corrugation," by J. A. PANTON, Associate Member.
April 18.—"Flexibles, with Notes on the Testing of Rubber," by Professor A SCHWARTZ, Member.
" 25.—"Depreciation," by R. HAMMOND, Member of Council.
May 2.—"The Use of Wooden Poles for Overhead Power Transmission," by C. WADE.
" 9.—"Telephonic Transmission Measurements," by B. S. COHEN, Associate Member, and G. M. SHEPHERD.
" 23.—"The Present State of Direct-Current Design as Influenced by Interpoles," by F. HANDLEY PAGE and FIELDER J. HISS, Students.
" 23.—"Hot-wire Wattmeters and Oscillographs," by J. T. IRWIN, Associate Member.

In addition to the above-mentioned papers the following have been accepted as "Original Communications" and printed in the Journal :—

"The Analysis of the Magnetic Leakages in Induction Motors," by A. BAKER, Associate, and J. T. IRWIN, Associate Member.

"On a Method of Plotting the Hysteresis Loop for Iron with an Application to a Transformer," by Dr. GISBERT KAPP, Vice-President.

LOCAL SECTIONS.

The Committees of the six Local Sections of the United Kingdom and that of the Cape Town Local Section have also been energetically carrying on the work of the Institution during the past Session. Since October 51 Meetings have been held in the several centres, namely, at Birmingham 7, at Dublin 7, at Glasgow 7, at Leeds 7, at Manchester 10, at Newcastle 6, and at Cape Town 7. The following are the papers read at each place, and those marked with an asterisk have been accepted up to the present for publication in the *Journal* :—

BIRMINGHAM.

1906.
*Nov. 21.—Chairman's Address, by R. A. CHATTOCK, Member.
*Dec. 12.—"The Heating Coefficient of Magnet Coils," by G. A. LISTER, Associate Member.

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1907.

*Jan. 16.—"Recent Improvements in Electric Lighting," by A. H. BATE, Associate Member.

*Feb. 13.—"Central Station Economics, their Study, and what it Promises in the way of Cheaper Supply," by A. M. TAYLOR, Member.

April 10.—"Some Considerations Involved in the Design of the Switch Gear for the Summer Lane Generating Station," by J. E. WOODBRIDGE.

CAPE TOWN.

1906.

Chairman's Address, by A. S. GILES, Member.

*June 11.—"Modern Transformer Design," by H. BOHLE, Member.

*July 23.—"Electric Lighting of Trains," by J. DENHAM, Member.

Nov. 3.—"Electricity *versus* Gas," by E. G. CLIFFORD JONES, Member.

* " 12.—"Three-phase Electric Power Transmission," by R. E. MANSEL, Associate

" 29.—"Electric Motor Driving," by C. PROCTOR BANHAM, Member.

"Electrical Contractor's Work at the Cape," by A. VAUX, Associate Member.

DUBLIN.

1906.

Nov. 8.—Chairman's Address, by A. W. WHIELDON, Member.

*Dec 6.—"Some Notes on the Breaking of Trolley Wires," by P. S. SHEARDOWN, Member.

" " —"Notes on Testing of Electric Meters," by W. TATLOW, Associate Member.

1907.

*Jan. 10.—"Note on Suction Producer Plant," by A. E. PORTE, Member.

Mar. 7.—"The Effect of High Efficiency Lamps on the Electric Lighting Industry," by W. TATLOW, Associate Member.

April 11.—"The Technical Training of Electrical Artisans," by C. P. C. CUMMINS, Associate Member.

GLASGOW.

1906.

*Nov. 13.—"Some Phenomena of Commutation," by Professor F. G. BAILY, Member, and W. S. H. CLEGHORNE.

Dec. 11.—"Fuel Economy," by H. B. MAXWELL, Member.

1907.

*Feb. 12.—"Remote Control High Tension Switch Gear," by F. WALKER, Associate Member.

*Mar. 12—"Stores and Cost Keeping for Electricity Supply Undertakings," by D. DENHOLM.

* " " —"The Pay Sheet," by R. B. MACCALL.

April 9.—"Illumination and Some Illuminants," by J. D. MACKENZIE, Associate

*May 14.—"A New Leading-in Conductor for Electric Lamps," by C. O BASTIAN, Member.

LEEDS.

1906.

*Oct. 25.—Chairman's Address, by G. WILKINSON, Member.

" " —"Recent Practice in Overhead Equipment," by R. H. CAMPION, Associate Member.

*Nov. 22.—"Regenerative Control of Electric Tramcars and Locomotives," by A. RAWORTH, Associate Member.

Dec. 13.—"Practical Photometry and its Value," by H. T. HARRISON, Member.

1907.

Jan. 24.—"Suction Gas Engines and Gas Plants," by H. CAMPBELL, Associate.

Mar. 21.—"Notes on Underground Mains," by W. M. ROGERSON, Associate Member.

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MANCHESTER.

1906.
*Nov. 20.—Chairman's Address, by T. L. MILLER, Member.
*Dec. 4.—"Rotary Converters *versus* Motor Generators," by M. WALKER, Associate.
„ 18.—"Cheapened Methods of Electrical Distribution," by J. H. C. BROOKING, Associate Member.

1907
*Jan. 8.—"Magnetic Leakage and Its Effect in Electrical Design," by W. CRAMP, Associate Member.
„ 22.—"Large Gas Power Plants," by C. E. DOUGLAS, Associate Member.
*Feb. 5.—"Magnetic Oscillations in Alternators and their Bearing upon the Design," by G. W. WORRALL, Associate Member.
* „ 19.—"Some New Flywheel Storage Systems," by A. P. WOOD, Member.
Mar. 5.—"Breakdowns of Electrical Machinery," by L. FOSTER, Member.
* „ 19.—"A New Type of Induction Motor," by L. J. HUNT, Associate Member.
*April 9.—"Experimental Determination of the Losses in Motors," by C. F. SMITH, Associate Member.

NEWCASTLE.

1906.
*Nov. 19.—Chairman's Address, by H. L. RISELEY, Associate Member.
Dec. 10.—"Three-phase Alternating Currents," by J. S. BARNES, Associate Member.

1907.
Jan. 14.—"Points in Power Station Design and Operation," by E. P. HOLLIS, Student.
*Feb. 4.—"Electric Power Installation at Grangesberg Iron Mines, Sweden," by G. RALPH, Member.
* „ 25.—"Train Lighting," by H. HENDERSON, Associate Member.
Mar. 18.—"The Insulation of Electrical Appliances," by O. J. WILLIAMS, Student.

The best thanks of the Institution are due to the Chairmen, the Committees, and the Local Honorary Secretaries, who devote much time and personal service to the organising of the Meetings and who have used their influence in obtaining these papers.

At the Annual Dinners of the Sections there has been a large attendance of members and distinguished guests. Invitations were in every case accepted by the President and other Members of Council who were fortunate in having these opportunities for meeting many of the members residing in the Provinces.

SALOMONS SCHOLARSHIP.

The Council have awarded two Salomons Scholarships, value £50 each, to:—

Mr. P. E. PÉRONNE, of the Finsbury Technical College.
Mr. R. E. NEALE, of the Central Technical College.

DAVID HUGHES SCHOLARSHIP.

One David Hughes Scholarship, value £50, has also been awarded to:—

Mr. E. MALLET, of University College, London.

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Annual Premiums.

The following premiums for papers and communications have been awarded by the Council this year. In accordance with precedent, in deciding upon the awards, the Council have not taken into account papers contributed by Members at present holding office on the Council.

The Institution Premium, value £25,
to Mr. C. C. Paterson (Associate Member) for his paper "Investigations on Light Standards and the Present Condition of the High-Voltage Glow Lamp."

The Paris Electrical Exhibition Premium, value £10,
to Professor J. Epstein (Foreign Member) for his paper "Testing of Electric Machinery and of Materials for its Construction."

An Extra Premium, value £10,
to Mr. W. Cramp (Associate Member) for his paper "Magnetic Leakage and its Effect in Electrical Design."

An Extra Premium, value £10,
to Mr. T. H. Schoepf (Member) for his paper "Single-phase Railway Motors and Methods of Controlling Them."

An Extra Premium, value £10,
to Professor A. Schwartz (Member) for his paper "Flexibles, with Notes on the Testing of Rubber."

An Extra Premium, value £10,
to Dr. W. M. Thornton (Member) for his paper "The Distribution of Magnetic Induction and Hysteresis Loss in Armatures."

An Extra Premium, value £10,
to Mr. C. Wade for his paper "The Use of Wooden Poles for Overhead Power Transmission."

The Fahie Premium,
to Mr. B. S. Cohen (Associate Member) and Mr. G. M. Shepherd for their paper "Telephonic Transmission Measurements."
Each to receive £10.

An Original Communication Premium,
to Mr. A. Baker (Associate) and to Mr. J. T. Irwin (Associate Member) for their communication "The Analysis of the Magnetic Leakages in Induction Motors."
Each to receive £5.

Students' Premiums.

A First Students' Premium, value £10, to Mr. W. Browning (Manchester) for his paper "Further Notes on Conductivity."

A First Students' Premium, value £10, to Mr. E. A. Watson (Birmingham) for his paper "A Simple Method of Measuring Sparking Voltages."

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A Second Students' Premium, value £5, to Mr. R. J. Kaula (London) for his paper "The Equipment of Steam Turbine Generating Stations."

A Second Students' Premium, value £5, to Mr. E. W. Moss (London) for his paper "Electric Valves."

A Second Students' Premium, value £5, to Mr. R. Rankin (Glasgow) for his paper "An Elementary Paper on the Induction Motor."

As in previous years, papers which were received too late for consideration in awarding premiums in 1906 have been taken into account this year. Papers, others than those read before the Students' Section, which were not in type by the end of April, 1907, have been reserved for consideration next year.

Students' Section.

During the session the Students' Section has held nine meetings in the library of the Institution, at which a number of papers have been read and discussed. At the opening meeting of the session an address to the students was delivered by Dr. C. V. Drysdale on the subject of "The Electrical Industry at Home and Abroad." The Students' Committee also arranged a series of visits to works, laboratories, and other places of interest, and they are now engaged in organising a visit to Switzerland to take place next July, when they hope to have an opportunity of seeing the large electrical engineering works and other undertakings in the neighbourhood of Zurich.

The Manchester Branch of the Students' Section has completed its third session, having held nine meetings and having also paid a series of visits to works and engineering undertakings. At the opening meeting of the session in Manchester an address was given to the Students by Dr. E. W. Marchant on "The Training of an Electrical Engineer."

Meetings have also been held by the Glasgow Branch of the Students' Section for reading and discussion of papers, under the Chairmanship of Professor Magnus Maclean.

The five Students' papers which were awarded a premium have been printed in the Journal.

Wiring Rules.

The important work of revising the Wiring Rules has been carried to a successful conclusion, and the new edition was issued in April. Bearing in mind the desirability of adopting rules of a character which would be universally acceptable, the Council entrusted the revision to a Committee on which were represented the Municipal Electrical Association and the Electrical Contractors' Association, besides containing representatives of the Institution and the electrical engineers of two of the leading Fire Offices, both of whom are members of the Institution; Mr. C. P. Sparks, Vice-President, acted as Chairman. The Cablemakers' Association and the Engineering Standards Committee co-operated in the work of revision, and valuable help was also

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given by Professor A. Schwartz, of the Manchester Municipal School of Technology, in making tests. With a view to meeting the continual developments in the electrical industry the Council have appointed the Wiring Rules Committee a standing Committee, and any criticisms or specific amendments which members may desire to send in will be considered when the rules are periodically revised. It is satisfactory to note that the new rules have been adopted by 35 Fire Offices, and accepted as standard practice by the Incorporated Municipal Electrical Association and by a large number of supply companies in London and the Provinces.

"SCIENCE ABSTRACTS."

In the publication of *Science Abstracts* the Council has continued to receive the assistance and support of the Physical Society of London, in accordance with the terms of the agreement entered into two years ago with that body. The American Institute of Electrical Engineers has also co-operated in extending the sphere of usefulness of *Science Abstracts* by bringing it prominently to the notice of its members, and the American Physical Society distributes Section (A) to all belonging to the Society. The number of subscribers among the members of this Institution also continues to show an increase, while it is highly satisfactory to note that the amount realised by sales to the public during 1906 was £420.

The Committee of Management, of which Mr. J. E. Kingsbury is the Chairman, is to be congratulated upon the increased economy in the cost of producing the publication. Under their control, and by close attention to detail, the contribution from the Institution has been reduced from £676 in 1905 to £394 in 1906.

In the course of 1906, 2,171 and 1,481 abstracts were published for the two Sections "Physics" and "Electrical Engineering" respectively (1,216 pages in all). Abstracts of papers are printed as soon after publication as is compatible with proper referencing to the pages where the original article occurs.

VISIT OF KINDRED INSTITUTIONS.

The arrangements for receiving representatives of the Electrotechnical Associations of other countries which were in progress at this time last year were successfully carried out. In presenting a brief report of the visit the Council feel it their duty in the first place to congratulate the Institution upon the success which, with the generous aid of the members, attended the efforts of the Entertainments Committee and of the Committee of Organisation. The best thanks of the Council are especially due to those members who assisted by their personal service and financial support, to the firms who also contributed largely to the Entertainments Fund and threw open their works to the visitors, and to the Chairmen and members of the Local Sections Committees who undertook the organisation of the programme in the cities visited on the circular tour, and spared no effort to ensure a hospitable welcome to the guests. Further, to the Lord Mayor and Corporation

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of Birmingham; to the Lord Mayors, Corporations, and Electricity Committees of Manchester and Liverpool; to the Mayor and Corporation and Electricity Committee of Salford; to the Lord Provosts, Corporations, and Electricity Departments of the cities of Edinburgh and Glasgow; to the Lord Mayor, Corporation, and Electricity Committee of Leeds, and to the Mayor and Corporation of Harrogate for the welcome accorded to the guests within their cities, and for the cordial hospitality extended on all sides. The thanks of the Institution have also been given to the Universities of Birmingham, Manchester, Liverpool, Glasgow, and Leeds. Finally, special acknowledgments were also made to Messrs. Babcock & Wilcox, who organised a whole day's excursion on the Clyde, to which all the members of the party making the circular tour were invited. The excursion took place on Tuesday, July 3rd—the second day of the stay in Glasgow—on the turbine steamer *Queen Alexandra.*

The Associations represented were as follows:—

The *American Institute of Electrical Engineers*, represented by Mr. S. S. Wheeler, President; Mr. J. W. Lieb, Junr.; Mr. C. O. Mailloux; Mr. R. W. Pope, Secretary, besides 34 members with 14 ladies	52
The *Canadian Electrical Association*, represented by Professor L. A. Herdt; Professor R. B. Owens	2
The *Société Internationale des Electriciens*, represented by Mr. Brylinski; Mr. Carpentier; Mr. Hospitalier *; Mr. Janet; Mr. Pollard, besides 19 members with 9 ladies	32
The *Associazione Elettrotecnica Italiana*, represented by Mr. G. Semenza, General Secretary; Mr. G. Barzanó; Mr. M. Bonghi, besides 32 members with 7 ladies	42
The *Elektrotechnischer Verein*, represented by Dr. E. Naglo; Dr. E. Rosenberg, besides 27 members with 7 ladies ...	36
The *Verband Deutscher Elektrotechniker*, represented by (including representatives of firms) Dr. E. Budde, President; Professor Klingenberg; G. Dettmar, General Secretary, besides 39 members with 6 ladies	48
The *Schweizerischer Elektrotechnischer Verein*, represented by Professor J. L. Farny, besides 14 members	15
Total	227

The proceedings opened in London on Monday, June 25th. After an informal reception on arrival at the Hotel Cecil, the visitors spent the afternoon in an excursion to the National Physical Laboratory, Teddington, where, by the kind invitation of the Committee and the Director, they attended the ceremony of opening the new Electrotechnical Laboratories by the Right Hon. R. B. Haldane, H.M. Secretary of State for War.

* During April last the Council learned with deep regret of the sudden death of Mr. Hospitalier.

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In the evening a banquet in honour of the visitors was given at the Hotel Cecil by the General Reception Committee and members of the Institution, Mr. John Gavey, C.B., President, presiding, at which the Right Hon. Sidney Buxton, Postmaster-General, and Mrs. Buxton, besides many other distinguished guests, were present. Mr. G. Semenza availed himself of the opportunity to present to the Institution on behalf of the Italian Electrical Association a handsome bronze bust of Alessandro Volta, which now occupies a prominent place in the library of the Institution (see photograph). A suitable acknowledgment of the gift, in the form of an illustrated address of thanks, has been sent to the Italian Association.

On Tuesday, June 26th, the following places and works of interest to electrical and telegraph engineers were visited by various parties: The General Post Office, Telegraphs and Telephones; the London Wall Exchange of the National Telephone Company; the Greenwich Generating Station of the London County Council (to which latter place the visitors were conveyed by special electric tramcars of the London County Council); the Bow Generating Station of the Charing Cross, City, and West End Electric Supply Company; the Lot's Road Generating Station of the Underground Electric Railways Company of London; and the Shepherd's Bush Generating Station of the Central London Railway Company. The parties to Greenwich, after luncheon at the Ship Hotel, visited the Royal Naval College, the Greenwich Hospital, and the Royal Naval Museum. Invitations were also given to a reception at the Observatory. In the afternoon, the return journey was made up the river in steamers of the London County Council. The parties to the West End were entertained to luncheon at the Welcome Club in the Austrian Exhibition, Earl's Court, after which a number of the visitors were conducted by Mr. H. Hirst over the Robertson Lamp Works of the General Electric Company.

While the visits were in progress in the morning the ladies of the party made a tour through London in motor cars, visiting places of interest under the guidance of a Ladies' Committee of which Professor J. D. Cormack kindly acted as Secretary.

In the evening the Annual Conversazione was held at the Natural History Museum, at which the President and Mrs. Gavey, supported by the President Elect and Mrs. Glazebrook, received the guests of the Institution and the members.

On Wednesday, June 27th, an excursion for the day was made to Windsor, where, by permission of His Majesty the King, the visitors were conducted over the private apartments of the Castle. The party, numbering about 350, afterwards lunched at the White Hart Hotel, and were conveyed up the Thames on steam launches to Cookham and back.

It was during the 26th and 27th of June that the Inaugural Meeting of the International Electrotechnical Commission took place, which is referred to fully in the Presidential Address and later on in this Report.

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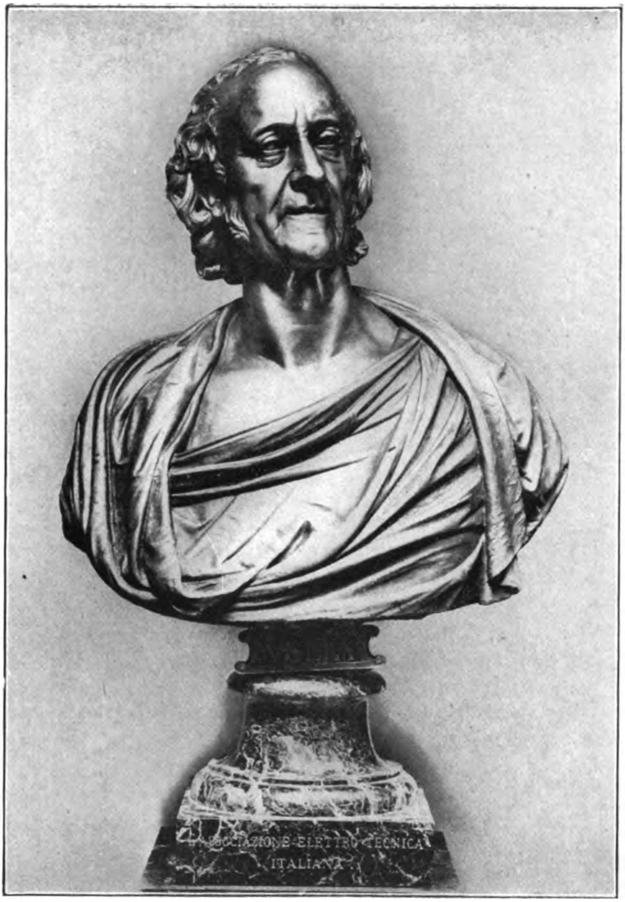

Bust of Volta.

Presented to the Institution by the Italian Electrical Association.

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By kind permission the following institutions, laboratories and works were thrown open to the visitors during their stay in London

The Board of Trade Electrical Standards Laboratory; the Central Electric Supply Company; the City and Guilds Technical College; the City and South London Railway; the Electrical Standardising, Testing and Training Institution, Faraday House; the Borough of Fulham Electricity Department; Messrs. Johnson & Phillips; the London Electric Supply Corporation; the Metropolitan Electric Supply Company; the Morgan Crucible Company; the Northampton Institute; the Robertson Lamp Works; Messrs. Siemens Bros. & Co.; the Telegraph Construction and Maintenance Company; the Western Electric Company; and the Westminster Electric Supply Corporation.

On Thursday, June 28th, a party of the guests, about 180 in number, under the guidance of the President, accompanied by Mrs. Gavey and some 30 members of the Entertainments Committee, left London for the purpose of making a tour through those centres in the provinces at which a Local Section is established. The whole round journey was performed in a special first-class train of the London and North-Western Railway Company. Influential Local Reception Committees were formed by the Chairmen and Committees of the Local Sections, and the under-mentioned works and places of interest were visited in the cities and towns passed through :—

Rugby—

The British Thomson-Houston Company, Ltd.
Messrs. Willans & Robinson, Ltd.

Birmingham—

Messrs. Belliss & Morcom, Ltd.
The Summer Lane Electric Supply Station of the Birmingham Corporation.
Messrs. Elkington & Co., Ltd.
The Metropolitan Amalgamated Carriage and Wagon Company, Ltd.
The Wolseley Tool and Motor Company, Ltd.
General Electric Company's Carbon Works, Witton.
The Birmingham Small Arms Company, Ltd.
The University.

Manchester—

The Stuart Street Electricity Works of the Manchester Corporation.
The British Westinghouse Electric and Manufacturing Company, Ltd.
The Ship Canal Works.

Liverpool—

The Lister Drive Power Station.
The Liverpool Overhead Electric Railway.
The Formby Power Station of the Lancashire and Yorkshire Railway.
The University.

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Glasgow—

The Pinkston and Port Dundas Electricity Stations of the Glasgow Corporation.

The Yoker Power Station of the Clyde Valley Electrical Power Company.

Clyde Bank Ship Yard (Messrs. John Brown & Co., Ltd.).

Dalmuir Ship Yard (Messrs. W. Beardmore & Co., Ltd.).

The Singer Manufacturing Company, Ltd.

North British Locomotive Company, Ltd.

Fairfield Shipbuilding and Engineering Company, Ltd.

Messrs. W. Beardmore & Co.'s Parkhead Forge.

Messrs. Babcock and Wilcox, Ltd.

Edinburgh—

Dewar Place and Macdonald Road Power Stations of the Edinburgh Corporation.

Newcastle-upon-Tyne—

Messrs. Armstrong's Elswick Works.

Messrs. J. H. Holmes & Co., Ltd.

Messrs. C. A. Parsons & Co.

Messrs. Swan and Hunter and Wigham Richardson's Ship Yards.

Carville Power Station of the Newcastle Electric Supply Company, Ltd.

Wallsend Slipway Engineering Company, Ltd.

Locomotive Works of the N.E. Railway Company.

Messrs. Ernest Scott and Mountain, Ltd.

Power Station of the Newcastle and District Electric Light Company.

Power Station of the Newcastle Corporation Tramways.

Leeds—

Electricity Works, Tramway Power Station, and Car Sheds of the Leeds Corporation.

Messrs. Greenwood and Batley, Ltd.

Messrs. Kitson & Co.

The Leeds Copper Works.

The Hunslet Engine Works.

The Yorkshire Electric Power Station.

Leeds University.

On Saturday, July 7th, the whole party made an excursion under the guidance of Mr. G. Wilkinson, Chairman of the Leeds Local Section, to Harrogate, and thence to Fountains Abbey, where luncheon was served in the cloisters. Access to the grounds was given by special permission of the Right Hon. the Marquess of Ripon.

With the permission of all the authorities concerned, descriptions of the institutions, laboratories, and works visited both in London and in the provinces were published in the form of a series of handbooks, dealing respectively with (1) London, (2) Birmingham and Leeds, (3) Manchester and Liverpool, (4) Glasgow, Edinburgh, and Newcastle, including also the districts round about these cities. In compiling the

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series much valuable assistance was rendered by the *Electrical Engineer*, the *Electrical Review*, the *Electrical Times*, and the *Electrician*, the editors of which devoted considerable time and labour to the work of collecting material and preparing it for publication.

The party returned to London on Saturday, July 7th, and there dispersed.

International Electrotechnical Commission.

It was reported at the last Annual General Meeting that steps were in progress towards the formation of an International Commission to deal with the standardisation of nomenclature and the ratings of machinery. In his Presidential Address, delivered at the opening meeting of the session, the President announced that the Commission had been inaugurated at a meeting of delegates from various countries, held in the latter part of June, during the time of the visit of the Kindred Institutions. A brief account of the scheme and the rules under which the Commission is constituted will be found in that Address, which has now been printed in the *Journal*.* Lord Kelvin was appointed the first President of the Commission and Colonel R. E. Crompton, C.B., the first Hon. Secretary. The Council gave its adherence to the scheme and appointed the first British Local Committee with the object of preparing recommendations to the Commission. The names of those forming this Committee are also given in the President's Address above referred to. Mr. C. le Maistre, Assistant Secretary to the Engineering Standards Committee, has been appointed the Secretary of the Committee, and the work was initiated by the appointment of a Sub-Committee on Nomenclature, consisting of the following members: Mr. A. P. Trotter (Chairman), Colonel R. E. Crompton, C.B., Mr. W. Duddell, F.R.S., Mr. M. B. Field, Mr. J. Gavey, C.B., Dr. R. T. Glazebrook, F.R.S., Mr. R. Hammond, and Dr. S. P. Thompson, F.R.S.

Up to the present time the Sub-Committee has held three meetings.

Engineering Societies' Building, New York.

In connection with the opening of the new Engineering Societies' Building in New York, in which the American Institute of Electrical Engineers is now accommodated, with other technical institutions, a communication was received from the Committee in charge of the arrangements, inviting the Council to send a delegation to represent the Institution at the ceremonies of dedication. The Council accordingly appointed Sir William H. Preece, K.C.B., F.R.S., Past President, to act as the representative of the Institution on the occasion, and a cablegram was despatched to him conveying the greetings and congratulations of the Council to the sister Institute on April 16th, the opening day. The message was duly delivered by the Institution's

* Presidential Address, by Dr. R. T. Glazebrook, F.R.S., *Journal of the Institution of Electrical Engineers*, vol. 38, 1907, p. 11.

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representative, who reports that great success attended the proceedings.

ANNUAL DINNER.

The Annual Dinner of the Institution was held at the Hotel Cecil on December 4, 1906. The President (Dr. R. T. Glazebrook, F.R.S.) presided, and many distinguished guests were present, the company numbering altogether 350.

BENEVOLENT FUNDS.

The capital account of the Benevolent Fund of the Institution showed a considerable increase at the end of 1906, as compared with the state of the Fund at the end of 1905. On December 31, 1906, the Capital Account of the Fund stood at £2,532, as against £2,021 at the end of 1905. As reported last year, the increase is largely due to the donation of £350 received from the Organising Committee of the Electrical Exhibition at Olympia in 1905. The Committee of the Electrical Engineers' Ball gave again, in accordance with their generous custom, a donation of £25 from the surplus at their disposal. The best thanks of the Institution are due to these and to the other donors and subscribers who have contributed to the Fund during the past year. One grant in aid was made during the year 1906 under the rules of the Committee.

From the Wilde Benevolent Fund, to which reference is made in the Hon. Treasurer's Report on the accounts, no grant has been made during the past year.

ANNUAL ACCOUNTS.

The accounts for 1906 are submitted in somewhat greater detail than formerly, and it is trusted that the new form will commend itself to the members. A Report to Council by Mr. R. Hammond, the Hon. Treasurer, on behalf of the Finance Committee, shows that the balance carried to the General Fund at the end of 1906, being excess of income over expenditure, was £3,548 15s., as compared with the corresponding amount for 1905, £3,302 15s. 2d., the increase for 1906 being £245 19s. 10d.

Balance Sheet.—The balance sheet sets out the total investments other than the investments of the Trust Funds. It will be seen that the total assets amounted to £41,659 5s. 1d. against which are to be set liabilities amounting to £1,215 5s. 1d., leaving as the net assets of the Institution £40,444, out of which the investments (other than the Buildings and Building Site) and cash amount to £19,449 6s. 4d.

Trust Funds.—The only alteration in the investments of the Trust Funds during the year has been the investment of £250 19s. 9d. in North-Eastern Railway 4 per cent. Guaranteed Stock on behalf of the Wilde Benevolent Trust Fund.

Life Compositions.—No alteration has taken place in this Fund during the current year, and it still stands at £5,581 13s.

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Entrance Fees.—This fund is for the first time set out separately, and certain of the investments which formerly appeared under the head of General Fund have been allocated to the Entrance Fees Fund. It will be noticed that the Fund has increased during the year by £569 8s., and that the total now stands at £3,867 11s. 6d.

Building Fund.—This Fund has increased during the year to the extent of £875 5s. 8d., the increase having been contributed by the revenue from the property, the subscriptions, and sundry other items. Since the close of the year £1,447 1s. 9d. out of the credit balance of £1,471 6s. 3d. has been invested in the purchase of £1,000 South-Eastern Railway 5 per cent. Debenture Stock.

General Fund.—The investments on account of this Fund during the year amounted to £3,522 19s., and the Fund now stands at £10,221 17s. 2d.

The investments which appear in the accounts at cost price with a book value of £18,714 2s. 11d. had a value of £16,819 at the current market prices of the day on the 30th of April.

Library.—This account is now brought up in a form which sets out the outlay for each separate year since 1900, and also particulars of the provision for depreciation allowed during the same years. Hitherto it has been customary to write off 5 per cent. for depreciation, which percentage is increased for the year under review to 10 per cent.

LIBRARY.

The work of reorganisation of the Library has been continuously carried on during the past year under the able supervision of the same Sub-Committee, consisting of Mr. W. Duddell, F.R.S., Mr. T. Mather, F.R.S., and Dr. S. P. Thompson, F.R.S. A report on the condition of the Library was presented by this Committee to the Council in October, showing what works it was necessary to acquire to make the collection of electro-technical literature complete. The report was accompanied by a list containing the titles of 1,623 works, including those of British, Continental, and American authorship. The works on this list were publications dating from the beginning of the last century to the end of 1905. As the Council felt that the possession of a complete Library is essential to the Institution, they authorised the expenditure of a sum of £650, to be spread over three years, beginning with 1906, with the object of purchasing these books, and apart from this special grant it was also agreed that the yearly grant of £75 hitherto authorised as the amount to be spent annually on new books and binding should be increased to £150.

The Sub-Committee in the preparation of this report held 54 meetings altogether. The number of meetings held since the presentation of the report in October to the end of this Session is 7.

Of the books contained in the above-mentioned list 398 have already been purchased out of the special grant of £650. In addition to these the number of new books purchased since June 1, 1906, out of the annual grant is 55, and there have been presented by

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members, publishers, and societies 494 books and pamphlets. The total number of works in the Library, including the Ronalds Collection, is now about 10,048, but in counting them the Proceedings of Societies and periodicals have been each regarded as one work, although in most cases they consist of many volumes.

The best thanks of the Institution are due to all members and others who have presented copies of their writings, and the Council hopes that such members as are publishing or have published new books or new editions of books will continue the practice of presenting copies of these, as the Committee is thereby continuously assisted in the work of keeping the Library up to date.

The number of members and visitors using the Library during the past twelve months has been 454.

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

BRITISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Civil and Mechanical Engineers' Society, Transactions.
Engineering Association of New South Wales.
Faraday Society, Transactions.
Greenwich Magnetical and Meteorological Observations.
Indian Telegraph Department, Administration Reports.
Institute of Chemistry, Proceedings.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
Liverpool Corporation Tramways, Annual Reports.
Liverpool Engineering Society, Proceedings.
Manchester Literary and Philosophical Society, Memoirs and Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Reports.
North-East Coast Institution of Engineers and Shipbuilders, Transactions.
North of England Institute of Mining and Mechanical Engineers' Transactions.
Physical Society, Proceedings.
Röntgen Society, Journal.

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Royal Dublin Society, Transactions and Proceedings
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Quarterly Journal.
Royal Scottish Society of Arts, Transactions and Journal.
Royal Society, Proceedings.
Royal United Service Institution, Journal.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
South Australia, Meteorological Observation Reports.
Surveyors' Institution, Transactions and Professional Notes.
Tramways and Light Railways' Association, Official Circular.

AMERICAN AND CANADIAN.

American Academy of Arts and Sciences, Proceedings.
American Institute of Electrical Engineers, Transactions and Proceedings.
American Institute of Mining Engineers, Transactions and Bi-Monthly Bulletin.
American Philosophical Society, Proceedings.
American Society of Civil Engineers, Proceedings.
American Society of Mechanical Engineers, Transactions.
Bureau of Standards, Washington, Bulletin.
Canadian Society of Civil Engineers, Transactions.
Engineers' Club of Philadelphia, Proceedings.
Engineering Society of Toronto, Transactions.
Franklin Institute, Journal.
Nova Scotia Institute of Science, Proceedings and Transactions.
Ordnance Department of the United States, Notes.
Philadelphia Electrical Bureau, Annual Reports.
Smithsonian Institution, Reports, Miscellaneous Collections and Contributions to Knowledge.
U.S. Official Patent Gazette.
Western Society of Engineers, Journal.

AUSTRIAN.

Kaiserliche Akademie der Wissenschaften, Wien, Sitzungsberichte.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

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DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.
Koninklijke Akademie van Wetenschappen, Amsterdam, Proceedings.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Bureau des Longitudes, Annuaire.
Société des Anciens Élèves des Écoles Nationales d'Arts et Metiers, Bulletin Technologique.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Annalen der Elektrotechnik.
Physikalische Technische Reichsanstalt, Abhandlungen.
Schiffbautechnische Gesellschaft, Jahrbuch.
Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.
Reale Accademia dei Lincei, Atti e Memorie.

RUSSIAN.

Section Moscovite de la Societé Impériale Technique Russe.

SWEDISH.

K. Svenska Vetenskaps-Akademien, Arkiv för Matematik, etc.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Engineering.

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Electrical Industries.
Electrical Magazine.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Engineer.
Engineering.
Engineering Magazine.
Engineering Review.
Engineering Times.
English Mechanic.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
International Marine Engineering.
Iron and Coal Trades Review.
Light Railway and Tramway Journal.
Mechanical Engineer.
Mining Journal.
National Telephone Journal.
Nature.
Page's Weekly.
Philosophical Magazine.
Railway Times.
Royal Engineers' Journal.
Vulcan.

AMERICAN.

American Journal of Science.
American Telephone Journal.
Electric Journal.
Electrical Review.
Electrical World.
Electrochemical Industry.
Engineering News.
India Rubber World.
Journal of Electricity, Power and Gas.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Technology Quarterly.
Terrestrial Magnetism and Atmospherical Electricity.

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AUSTRIAN.

Elektrotechnik und Maschinenbau.

DANISH.

Teknisk Tidsskrift.

DUTCH.

De Ingenieur.

FRENCH.

Archives des Sciences Physiques et Naturelles.
L'Éclairage Électrique.
L'Electricien.
L'Industrie Électrique.
La Houille Blanche.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.
Portefeuille Economique des Machines
Revue Électrique.

GERMAN.

Annalen der Physik und Chemie.
Arkiv für Post und Telegraphie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Elektrische Bahnen.
Elektro-Ingenieur Kalender (Hirsch und Wilking).
Elektrotechnische und Polytechnische Rundschau.
Elektrotechnische Zeitschrift.
Elektrotechnischer Anzeiger.
Fortschritte der Elektrotechnik.
Glückauf.
Jahrbuch der Elektrochemie.
Physikalische Zeitschrift.
Sammlung Elektrotechnische Vorträge.
Technische Literatur.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

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ITALIAN.

L'Elettricista.
L'Elettricita.
Giornale del Genio Civile.
Il Nuovo Cimento.

SPANISH.

Anuario de Electricidad.
La Ingenieria.

SWISS.

Schweizerische Elektrotechnische Zeitschrift.

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The Institution of

STATEMENT OF INCOME AND
ENDED 31st

Dr.

EXPENDITURE.

	£	s.	d.	£	s.	d.
To MANAGEMENT :—						
Salaries	1,638	18	4			
Retiring Allowance	300	0	0			
Accountants' Fees	21	0	0			
Addressing	62	5	6			
Printing and Stationery	418	5	10			
Postage	704	0	5			
Telephone	26	10	0			
Travelling	49	8	4			
				3,220	8	5
" RENT, INSURANCE, LIGHTING, AND FIRING				680	13	3
" OFFICE REDECORATION				85	2	7
" PUBLICATIONS :—						
Journal	1,012	9	0			
"Science Abstracts"—						
Disbursements £1,749 15 8						
Less Receipts 1,355 15 5						
	394	0	3			
				1,406	9	3
" MEETINGS :—						
Advance Proofs, Refreshments, &c.	121	7	0			
Reporting	57	15	0			
				179	2	0
" LOCAL SECTIONS				582	5	8
" PREMIUMS				126	9	2
" INTERNATIONAL ELECTROTECHNICAL COMMISSION				189	14	7
" CONVERSAZIONE				302	14	7
" ANNUAL DINNER				64	19	8
" MUSEUM				20	0	0
" DEPRECIATION :—						
Library (10 %)	142	12	10			
Furniture (5 %)	23	8	3			
				166	1	1
" MISCELLANEOUS EXPENSES				68	14	7
" BALANCE carried to General Fund, being excess of Income over Expenditure				3,548	15	0
				£10,641	9	10

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Electrical Engineers.

EXPENDITURE FOR THE YEAR DECEMBER, 1906.

Cr.

INCOME.

	£ s. d.	£ s. d.
By Subscriptions		9,734 1 6
,, Dividends on Investments :—		
Life Compositions Fund	£169 9 0	
General and Entrance Fees Funds	298 16 7	
		468 5 7
,, Interest on Cash on Deposit		36 5 3
,, Journal :—		
Sales	157 5 11	
Advertisements	234 10 0	
		391 15 11
,, Wiring Rules		6 16 2
,, Model General Conditions for Contracts		4 5 5
		£10,641 9 10

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BALANCE SHEET,

Dr.

LIABILITIES.

				£	s.	d.
To Salomons Scholarship Trust Fund (Income)				9	17	8
„ David Hughes Scholarship Trust Fund:—						
Capital uninvested	1	5	0			
Income	28	3	7			
				29	8	7
„ Wilde Benevolent Trust Fund (Income)...				59	14	6
„ Life Compositions Fund				5,581	13	0
„ Entrance Fees Fund				3,867	11	6
„ Building Fund				20,732	3	4
„ Sundry Creditors				934	12	3
„ Local Sections:—						
Due to Hon. Sec. Birmingham Section ...	10	18	5			
do. do. Dublin do. ...	3	17	2			
				14	15	7
„ Subscriptions received in advance				168	1	6
„ Foreign Visit Fund				39	10	0
„ General Fund				10,221	17	2
				£41,659	5	1

ROBERT HAMMOND,
Honorary Treasurer.

G. C. LLOYD,
Secretary.

We beg to report that we have examined the above Balance Sheet and have inspected the Bankers' Certificates of Investments and the Title Deeds and the Balance Sheet is properly drawn up so as to exhibit a true its books. We hereby certify that all our requirements as Auditors have

ALLEN, BIGGS & CO.,
Chartered Accountants.
147, Leadenhall Street, E.C.

May 1, 1907.

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31st DECEMBER, 1906.

Cr.

ASSETS.

					£	s.	d.
By Life Compositions Investments (at cost)					5,555	12	0
„ Entrance Fees Investments „					3,719	12	11
„ Buildings and Building Site „					19,260	17	1
„ General Fund Investments „					9,438	18	0
„ Sundry Debtors					661	5	1
„ Local Sections :—							
Cash in hands of Hon. Sec. Glasgow Section	9	10	11				
do. do. do. Leeds Section ...	1	18	0				
do. do. do. Manchester ...	8	4	0				
do. do. do. Newcastle Section	20	15	10				
					40	8	9
„ Furniture					444	16	4
„ Library					1,283	15	10
„ Vellum Diploma Forms					5	4	5
„ Cash :—At Bankers'	1,169	4	5				
Petty Cash	24	9	10				
P. O. Savings Bank	55	0	5				
					1,248	14	8
					£41,659	5	1

Statements of Account with the Books and Vouchers of the Institution. We of the Tothill Street Property. In our opinion the Statements are correct, and correct view of the state of the affairs of the Institution as shown by been complied with.

H. ALABASTER, } *Honorary Auditors.*
SIDNEY SHARP, }

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SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1906...	100	0	0
„ Balance carried to Balance Sheet	9	17	8
	£109	17	8

DAVID HUGHES SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1906...	87	10	0
„ Balance carried to Balance Sheet	28	3	7
	£115	13	7

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
„ „ (transferred from Income)	244	16	0
	£1,744	16	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount transferred to Capital	244	16	0
„ „ Balance carried to Balance Sheet	59	14	6
	£304	10	6

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TRUST FUND.

	£	s.	d.
By Investments (at cost) :—			
£1,500 New South Wales 3½ % Stock	1,556	5	9
500 Cape of Good Hope 3½ % Stock	570	13	6
	£2,126	19	3

Cr.

TRUST FUND (Income).

Cr.

	£	s.	d.
By Balance (as per last Account)	40	1	2
„ Dividends received in 1906	69	16	6
	£109	17	8

TRUST FUND.

Cr.

	£	s.	d.
By Investment (at cost) :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

TRUST FUND (Income).

Cr.

	£	s.	d.
By Balance (as per last Account)	54	9	9
„ Dividends received in 1906	61	3	10
	£115	13	7

TRUST FUND.

Cr.

	£	s.	d.
By Investments (at cost):—			
£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
£215 North Eastern Railway 4 % Guaranteed Stock ...	250	19	9
	£1,744	16	0

TRUST FUND (Income).

Cr.

	£	s.	d.
By Amount (as per last Account)	255	14	7
„ Dividends received in 1906	43	12	8
„ Interest do. do.	5	3	3
	£304	10	6

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LIFE

Dr.

	£	s.	d.
To Amount (as per last Account)	5,581	13	0
	£5,581	13	0

ENTRANCE

Dr.

	£	s.	d.
To Amount (as per last Account)	3,298	3	6
" " received in 1906	569	8	0
	£3,867	11	6

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COMPOSITIONS.

Cr.

				£	s.	d.
By Investments (at cost):—						
£318	0	0	Cape of Good Hope 4 % Consolidated Stock	306	0	0
1,679	19	5	India 3½ % Stock	1,776	5	0
120	0	0	South-Eastern Railway 5 % Debenture Stock	204	16	6
355	5	10	Canada 3 % Stock	352	13	6
289	17	4	Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10
6	0	0	East Indian Railway Class "C" Annuity ...	185	1	9
87	0	0	Great Eastern Railway 4 % Consolidated Preference Stock	130	15	2
175	0	0	Great Eastern Railway 4 % Debenture Stock	251	5	5
5	6	4	Great Indian Peninsula Railway "B" Annuity	133	17	6
190	13	4	Metropolitan Water Board "A." Stock ...	207	17	9
520	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3
200	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0
29	0	0	Madras Railway 5 % Stock	44	9	4
60	0	0	South Indian Railway 4½ % Debenture Stock	88	1	4
30	0	0	Burma Railway Co.'s Stock	30	12	3
40	0	0	East Indian Railway 4½ % Debenture Stock ...	57	3	7
400	0	0	Natal Zululand Railways 3 % Debentures ...	351	1	0
350	0	0	New Zealand 3½ % Inscribed Stock	345	12	10
				£5,555	12	0
„ Balance			... ...	26	1	0
				£5,581	13	0

FEES.

Cr.

				£	s.	d.
By Investments (at cost):—						
£1,418	8	0	Midland Railway 2½% Consolidated Perpetual Preference Stock	1,200	0	0
918	3	2	India 3½ % Stock	973	17	10
410	0	0	East Indian Railway 4½ % Debenture Stock ...	586	1	7
800	0	0	North Eastern Railway 4 % Preference Stock ...	959	13	6
				£3,719	12	11
„ Balance			... ...	147	18	7
				£3,867	11	6

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Dr.

	£	s.	d.
To Amount (as per last Account)	19,856	17	8
„ Revenue from Property	623	10	6
„ Subscriptions	115	18	0
„ Return on Fire Policies	103	2	2
„ Interest on Deposit	24	3	6
„ Surplus from Vellum Diplomas	8	11	6
	£20,732	3	4

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FUND.

Cr.

	£	s.	d.
By Buildings and Building Site, 15 to 18, Tothill Street (as per last Account)	19,260	17	1
„ Balance	1,471	6	3
	£20,732	3	4

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GENERAL

Dr.

						£	s.	d.
To Amount (as per last Balance Sheet) ...	£7,423	2	2					
Less Estimated Value of Outstanding Subscriptions in 1905 Accounts written back ...	750	0	0					
						6,673	2	2
Add Excess of Income over Expenditure for 1906						3,548	15	0
						£10,221	17	2

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Cr.

			£ s. d.
By Investments (at cost):—			
£52 13 8	Great Indian Peninsula Railway "B" Annuity	1,239 17 9	
721 0 0	Madras Railway 5% Stock ...	1,114 14 0	
623 0 0	Great Western Railway 5% Preference Stock	999 18 1	
2,200 0 0	Natal Zululand Railways 3% Debentures	1,919 11 0	
650 0 0	New Zealand 3½% Inscribed Stock	641 18 2	
			5,915 19 0
„ Investments during 1906:—			
£1,100 0 0	Great Eastern Railway 4% Consolidated Preference Stock ...	1,266 18 9	
1,050 0 0	London and North Western Railway 4% Preference Stock ...	1,225 4 9	
700 0 0	Great Eastern Railway Metropolitan 5% Guaranteed Stock ...	1,030 15 6	
			3,522 19 0
			9,438 18 0
„ Balance			782 19 2
			£10,221 17 2

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LIBRARY.

Dr.

	£	s.	d.
To Amount (as per Balance Sheet)	1,283	15	10
	£1,283	15	10

Up to the year 1900 the value of books presented had been added to the Book Value of the Library, but since that date this practice has been discontinued.

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LIBRARY.

Cr.

				£	s.	d.
Value of Books and Pictures, as per Balance Sheet, December 31, 1900 (not including the Ronalds Library)				1,397	13	5
Outlay in 1901				24	19	0
" 1902				17	8	9
" 1903				44	8	1
" 1904				34	16	7
" 1905				45	2	10
				1,564	8	8
Less provision for Depreciation :—						
In 1901	£71	2	8			
" 1902	68	8	11			
" 1903	67	4	11			
" 1904	65	12	6			
" 1905	64	12	0			
				337	1	0
Value as per last Balance Sheet				1,227	7	8
Outlay in 1906				199	1	0
				1,426	8	8
Less 10 per cent. Depreciation for 1906				142	12	10
				£1,283	15	10

The year 1901 was the first year in respect of which depreciation was allowed for.

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The PRESIDENT: I now beg leave to move: "That the Report of the Council as presented be received and adopted, and that it be printed in the *Journal* of the Proceedings of the Institution." The Report has been distributed, but it is perhaps desirable just to call attention to two or three of the more important points. One important matter is referred to in the Report, the procedure in nominating candidates for election to the Council. It has been felt for some little time past that the period which elapses ordinarily between the date on which the names of candidates for election are announced and the date on which new names can be sent in by members of the Institution is somewhat short, and the Council trust that the procedure indicated, whereby the names suggested by the Council are communicated to the members some little time before their formal announcement at the meeting, will obviate that difficulty. With regard to the meetings and papers there is little, I think, I need say, except that the Institution is to be congratulated on the papers that have been read during the session and on the discussions that have taken place. One other point remains for mentioning, and that is the work that has been done by the Wiring Rules Committee. There is no doubt, I think, that the result of that work will be of very great value. It is most satisfactory to know that the new rules have now been adopted by thirty-five fire offices, and will practically become, I take it, the universal rules for fire insurance purposes. Members will remember that the Report goes back through the whole of the session, that is to say, from May of last year until the present date, and therefore covers the important visit of kindred institutions which took place during June and July last year. Some little account of that visit is given in the Report in order that we may have it incorporated in a formal manner in our transactions. The work of the International Electrotechnical Commission promises to be of very great value; and all the members of the Commission and those interested in the work are very deeply indebted to the Council for the very generous way in which they found the funds for setting the work of the Commission going. That is explained, I think, in the Report. With regard to the Benevolent Fund of the Institution, you will notice an announcement made in the Report of the Benevolent Fund Committee that the Committee hope during the present year to issue a notice referring to the work and the importance of that fund, in the hope, if possible, of getting a still larger increase in the subscriptions. The increase in donations this year is considerably over what it has been for the last few years, but that is entirely due to a generous donation of £350 received from the Organising Committee of the Electrical Exhibition at Olympia; the ordinary donations and subscriptions are, if anything, a trifle below what they were in the previous year. I will conclude with one short reference to the work of reorganisation of the Library which has been going on during the year, and has been so ably supervised by Mr. Duddell, the Chairman of the Committee, Mr. Mather, and Dr. Thompson. The Institution is very deeply indebted to those gentle-

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men for the work they have done; and all the members, I am sure, are glad to realise that the Council has decided to put at the disposal of the Library Committee in the future a somewhat larger sum than it has been the custom for some few years past to give to that purpose to help in the maintenance of our very admirable Library.

Mr. T. MATHER, F.R.S., seconded the motion, which was then put to the meeting and carried unanimously.

The PRESIDENT: I now have to move: "That the Statement of Accounts and Balance Sheet for the year ending December 31, 1906, as presented and circulated, be received and adopted."

Mr. R. HAMMOND: Mr. President and Gentlemen,—Those who have the Accounts will notice that on the first page there is the usual statement of the Expenditure and Income, resulting in a balance to the good on the year's operations of £3,548, which is £250 larger than the balance we were able to transfer to the General Fund last year. The Balance Sheet on the next page sets out for the first time the whole of the property of the Institution, including its various funds other than the Trust Funds. It will be noticed that the assets amount to £41,659. There is included in that figure the Building Fund asset; but other than the Building Fund asset, and the liabilities which there are on current account, the Institution has £19,500 to the good. The various funds are set out and speak for themselves. On page 773 it will be noticed there is a list of the investments under the Life Compositions Fund, that amount being one which we have to keep intact in order to cover the liability of those who have compounded for their annual fees. For the first time the Entrance Fees Fund is set out separately, and shows a separate investment. Obviously the entrance fees form a fund which should not be treated as a current fund, as we treat our various incomes from subscriptions, but should be treated as capital account; it therefore finds a place by itself, and it amounts to the substantial figures of £3,719. In addition to the Building Asset, the expenditure on the acquisition of the site in Tothill Street, there is the revenue from the property during the past year, and the subscriptions received, showing a balance to the good of £1,471, which amount has since been invested. The General Fund shows that, out of a total of £10,221, £9,438 has been invested. That fund, it will be noticed, is steadily growing larger, at the rate of about £3,500 per annum. The last item in the Accounts is that of the Library, which is this year set out in much larger detail than it has hitherto been; but the Council felt it would be wise to show somewhat in historical form what the outlays had been during the past few years in that respect. We go back in this case to 1900, and we propose to keep the account on this basis so that it will always show ten years' operations. We then show in the Account the provision for depreciation. Our custom hitherto has been to set aside 5 per cent., but we have altered that this year, and have set aside 10 per cent. for the depreciation of the Library, though, of course, there are those who say that the Library is worth very much more than the figure at which it stands in the books. I do not think there is any

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other item in the Accounts to which it is necessary to draw attention, and I therefore have much pleasure in seconding the President's motion, that the Accounts be received and adopted.

The PRESIDENT: In putting the motion, it is my duty to call attention to the Certificate of the Chartered Accountants and Hon. Auditors, set out at the bottom of the Balance Sheet, which runs as follows: "We beg to report that we have examined the above Balance Sheet and Statements of Account with the Books and Vouchers of the Institution. We have inspected the Bankers' Certificates of Investments and the Title Deeds of the Tothill Street Property. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the affair of the Institution as shown by its books. We hereby certify that all our requirements as Auditors have been complied with."

The motion for the reception and adoption of the Accounts and Balance Sheet was then put and carried unanimously.

Mr. W. M. MORDEY: Mr. President and Gentlemen,—We have heard from the Treasurer that we have something over £19,000 as a Building Fund, but we have no building. Some day we hope, I am sure, that we shall not have to pass the vote which it is put into my hands to propose; but in proposing it now, I need hardly say that we do so with a continuance of the gratitude we have always felt for the great kindness of the Institutions whose hospitality we have enjoyed. I have pleasure in proposing: "That the best thanks of the Institution be and are hereby given to the Council of the Institution of Civil Engineers and to the Council of the Society of Arts for the great privilege accorded to this Institution of placing their rooms at its disposal for the holding of their evening Meetings."

Mr. L. GASTER seconded the proposal, and the resolution was unanimously carried.

Mr. W. DUDDELL: Mr. President and Gentlemen,—I have very great pleasure in drawing attention to the work performed by some of the members of the Institution, who in a quiet way do a great deal of good —I refer to the Local Hon. Secretaries at home and abroad. They do a lot of hard work, of which we do not hear much, in getting together papers and collecting revenue, and in generally promoting the welfare of our Institution. I, therefore, have very much pleasure in proposing: "That the best thanks of the Institution be given to the Local Hon. Secretaries for their services during the past year."

Mr. W. M. MADDEN: I have much pleasure in seconding the motion.

The resolution was then put and carried unanimously.

Mr. R. KAYE GRAY: Mr. President and Gentlemen,—I have a very pleasant duty to perform, and that is to propose: "That the best thanks of the Institution be accorded to Mr. R. Hammond in recognition of the valuable services rendered by him during the past session in his office of Hon. Treasurer." I have acted during the past year as Chair-

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man of the Finance Committee, and have naturally been brought very much in contact with Mr. Hammond. I would like to say that amongst all our Committees, although some of them work very hard, there are very few members who have the interests of the Institution so much at heart as Mr. Hammond has. He shows it first of all in the hard work he does; he also shows it by the fact that he is willing at any time to come down here to attend to the affairs of the Institution. We are very much indebted to him for all he does for us, and I have very much pleasure in proposing the resolution.

Mr. W. DOBSON: I have much pleasure in seconding the motion. Mr. Hammond at all times has given every satisfaction, and has always impressed engineers with the fact that efficiency is one of his characteristics. I think our finances could not be in better hands than those of Mr. Hammond.

The resolution was then put, and carried with acclamation.

Mr. HAMMOND expressed his acknowledgments.

Mr. W. JUDD: I am entrusted with the pleasant duty of proposing a vote of thanks to our Hon. Auditors. They naturally give a great deal of time and attention to seeing that everything is run on the right lines and that the finances are accurate, and after doing that work they are able to give us their certificate at the end of the year saying that everything is kept in the best possible order. I have therefore much pleasure in proposing: "That the best thanks of the Institution be given to the Hon. Auditors (Mr. H. Alabaster and Mr. Sidney Sharp) for their valuable services during the past year."

The motion having been seconded by Mr. F. W. HEWITT,

The resolution was put and carried unanimously.

Mr. F. C. RAPHAEL: I understand that the Hon. Solicitors this year have not had a great deal of work to do. Unfortunately, perhaps, there have been no actions for libel in connection with the Institution *Journal*, and there has been no necessity for any drastic alteration in the Articles of Association. I hope, however, in a few years, following on what Mr. Mordey has said, they will have a great deal to do in drawing up agreements in connection with the building of our new home. I have much pleasure in proposing: "That the best thanks of the Institution be tendered to Messrs. Wilson, Bristows & Carpmael for their kind services in their capacity as Hon. Solicitors during the past year."

Mr. E. O. WALKER having seconded the resolution, it was put and carried unanimously.

The PRESIDENT announced that since, under the Articles of Association, no candidates other than those nominated by the Council had been put forward, the following were duly elected as the Council and Hon. Officers for 1907–8:—

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President:

To assume office in November, 1907.

THE RIGHT HON. LORD KELVIN, P.C., O.M., G.C.V.O., F.R.S.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents:

F. GILL.
COL. H. C. L. HOLDEN, R.A., F.R.S.
PROFESSOR G. KAPP.
C. P. SPARKS.

Members of Council:

W. DUDDELL, F.R.S.
S. EVERSHED.
H. E. HARRISON, B.Sc.
DR. E. HOPKINSON.
J. W. JACOMB-HOOD.
WALTER JUDD.
J. E. KINGSBURY.
W. M. MORDEY.
M. O'GORMAN.
G. W. PARTRIDGE.
W. H. PATCHELL.
S. L. PEARCE.
W. RUTHERFORD.
A. A. C. SWINTON.
C. H. WORDINGHAM.

Associate Members of Council:

ALBERT CAMPBELL, B.A.
J. HUNTER GRAY.
H. HUMAN.

Honorary Treasurer:

ROBERT HAMMOND.

Honorary Auditors:

H. ALABASTER.
SIDNEY SHARP.

Mr. R. HAMMOND: I do not think we should disperse until we have given a little expression of opinion with regard to our President. I think we owe the President a very great debt of gratitude for the hard work he has put in during the past twelve months. He has been busily engaged daily in connection with the work of the Institution; he has represented the Institution most worthily on more than numerous occasions, and wherever it has been possible to uphold the honour of the Institution, there the President has been. I have very much pleasure in proposing a vote of thanks to him for presiding to-day, and I would like to couple with it an expression of very great gratitude to him for his past year's work.

Mr. W. M. MORDEY: I would like to second Mr. Hammond's proposal, and I do so with very great pleasure. I have seen a good deal of Dr. Glazebrook's work as President, and I can truly say he has upheld the honour of the Institution, and has very worthily fulfilled the responsible office to which we elected him a year ago.

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The resolution was put to the meeting by Mr. HAMMOND, and carried with acclamation.

The PRESIDENT, in reply, said: Gentlemen, I thank you very cordially indeed for the kind way in which the motion was moved and seconded and accepted by you. It has been a great pleasure and a great privilege to me to act as your President for the past year. It has widened my views in many ways; it has brought me in contact with a number of men whom I hope in the years to come I may always count on as my friends; and it has shown me very clearly the importance and greatness of the work that is done by this Institution. I said when I took up the office that I esteemed it a great privilege; I can only say the same now; and I am glad to think that what little I have been able to do has been received in the way in which you have so kindly received it this afternoon.

The meeting then adjourned.

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OBITUARY NOTICES.

SIR BENJAMIN BAKER, K.C.B., K.C.M.G., F.R.S., died suddenly on May 19, 1907, at his residence, Bowdon Green, Pangbourne. Sir Benjamin Baker was the son of Mr. Benjamin Baker, of Co. Carlow, and at the time of his death was in his 67th year.

In his early years he was apprenticed to Mr. H. H. Price, a civil engineer in a large practice. He afterwards entered the service of the late Sir John Fowler, with whom he afterwards went into partnership, Among the many important engineering undertakings designed and carried out by Sir Benjamin Baker, the two great works with which his name will always be associated are the Forth Bridge and the Assouan Dam across the Nile. The Forth Bridge was the first structure of any magnitude to which the principle of the cantilever was applied, the two large spans measuring 1,710 feet. The work of building it occupied seven years, and at the opening in 1890 he was made a Knight Commander of St. Michael and St. George. On the completion of the Assouan Dam the honour of Knight Commandership of the Bath was conferred upon him, as well as a decoration by the Khedive. The full list of engineering works with which Sir Benjamin Baker was prominently connected would be too long to enumerate, though it would indicate the great variety and importance of his practice, as well as the remarkable success achieved in dealing with problems of novel character and difficulty. He was an adviser on the design of the Thames Tunnel at Blackwall; he repaired several historical bridges built by Telford. The vessel in which Cleopatra's Needle was conveyed from Egypt to this country was also designed by him. His connection with electrical engineering was chiefly in his capacity as Consulting Engineer for the tunnel of the Central London and other tube railways.

The Royal Society elected him a Fellow in 1890, honorary degrees were bestowed upon him by the Universities of Cambridge and Edinburgh, and honorary membership by the Irish Academy, and other bodies. He took a leading part in the work of the British Association, and in 1895 he attained the honour of election as President of the Institution of Civil Engineers. Up to his death he remained an active and influential member of the Council of that Institution and of the Council of the Institution of Mechanical Engineers. He was also made an honorary member of many colonial and foreign engineering societies. He was elected a Member of the Institution of Electrical Engineers in 1894.

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JOHN RICHARD BRITTLE died at his residence at Blackheath on February 25, 1907. He was a Whitworth Scholar, and after passing through a course of technical training at King's College, London, he gained Associateship of that College. He was for many years Assistant Telegraph Engineer in the service of Messrs. Siemens Bros. & Co., though at the time of his death he was living in retirement. He was elected an Associate of the Institution, then the Society of Telegraph Engineers, in 1874, and became Member in 1877.

WILLIAM ALEXANDER BRYSON died in July, 1906, at Leith. Mr. Bryson went to Leith in 1897, and was for some years Electrical Engineer to the Leith Corporation. He was responsible for the designing of the electric station and the carrying on of the work until early in 1901, when he resigned and began a private practice as consulting engineer. Since taking up private work in Leith he superintended installations of lighting and power in various public buildings. Mr. Bryson became a Member of the Institution in 1889.

LOUIS CASSIER was among those killed in the disastrous accident on the London and South-Western Railway at Salisbury on July 1, 1906. He was born in Boston, Massachusetts, in 1863, and was well known as the founder and publisher of *Cassier's Magazine*, the first issue of which appeared in New York in 1891. Three years later the London edition of this periodical began to be published, the English business being converted into a limited company in 1899. He also took over in 1903 the *Electrical Age*, a monthly magazine published in New York. He was connected with several of the learned and technical societies in England and America, and was elected an Associate of the Institution of Electrical Engineers in 1905.

WILLIAM RICHARD THOMAS COTTRELL died at Arosa, Switzerland, on February 4, 1907, in his 34th year. He was educated at Bristol, and matriculated at the London University in 1890, subsequently going through an electrical engineering course of instruction at the City and Guilds Central Technical College, South Kensington. After spending a short time of pupilage with Messrs. Veritys', Ltd., he served as an apprentice with Messrs. Easton, Anderson & Gouldon, Ltd., and remained in their service until 1898. For a short time he acted as Temporary Assistant on the staff of the London County Council, and then obtained an appointment as Assistant Engineer on the Construction Staff of the London United Tramways (1901), Ltd. In 1903 he became Chief Assistant Engineer to the Central London Railway, a post which he held until his health broke down. In the latter part of 1906 he was obliged to give up work, having been ordered abroad for the benefit of his health. Mr. Cottrell was an Associate Member of the Institution of Civil Engineers, and was elected an Associate of the Institution of Electrical Engineers in 1896. He was transferred to the class of Associate Members in 1899.

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GEORGE HERBERT SANDS DREWETT died of cholera on July 3, 1906, at Bangkok, in Siam. Mr. Drewett was a partner in the firm of Messrs. Drewett & Hood, of Bristol, until December, 1905, at which time the business was purchased by Messrs. T. Hood & Co., Ltd., Mr. Drewett becoming a Director. When this amalgamation took place, he accepted an appointment as Manager of the Bangkok Dock Company. He was elected an Associate Member of the Institution in 1901.

ERNEST ALBERT ELLICOT died in October, 1906, in his 43rd year. After serving an apprenticeship, he was appointed Engineer-in-Charge of the Taunton Corporation Electricity Supply Works. Subsequently he held the position of Assistant Engineer to the London Electric Supply Corporation, Ltd. He was elected an Associate Member of the Institution in 1900.

WILLIAM EDWARD LOUIS GAINE, General Manager of the National Telephone Company, died after a brief illness on June 18, 1907, at his residence in London. Mr. Gaine was born in London in 1851. After leaving school he was articled to Mr. Compton-Smith, of Lincoln's Inn Fields, and was in due course admitted as Solicitor of the High Court. In 1875, at the age of 23, he was appointed Town Clerk of the County Borough of Blackburn, Lancashire, and subsequently Clerk of the Peace. This appointment he held for seventeen years, during which time he achieved a high reputation among municipal officers for his ability and energy.

In 1892 he accepted the position of General Manager of the National Telephone Company. At that time the company did not include the whole of the United Kingdom in the scope of its operations, as the West of England and South Wales Telephone Company, the South of England Telephone Company, and the Telephone Company of Ireland were still in existence. These three companies were, however, amalgamated with the National Company shortly after Mr. Gaine's appointment as General Manager, and under his administration the company grew and prospered steadily. At the time he took the control the National Company's system served about 46,000 subscribers' lines and the staff numbered about 4,000 employees of all ranks. It now serves 377,883 subscribers and the staff numbers nearly 16,000. The company derived great advantage from Mr. Gaine's experience as a solicitor, when engaged in difficult and intricate negotiations of a legal character, and it is largely due to his skill and management that, in the face of many difficulties, the company has attained its present position. Mr. Gaine was a Member of the Incorporated Law Society, and was elected a member of the Institution of Electrical Engineers in 1893.

FREDERICK THOMAS HOLLINS died in February, 1907. He was Superintendent Telegraph Engineer in the service of the Great

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Eastern Railway Company at Liverpool Street, London, and was elected a Member of the Institution in 1891.

DAVID BERNARD INGRAM died in India in May, 1907, at the age of 30. He received his training as engineer at the Elswick Works of Sir W. G. Armstrong, Mitchell & Co., after which he spent four years at sea as marine engineer. In 1902 he became Assistant Engineer to the Bournemouth and Poole Electric Supply Company. He also held posts as Assistant Engineer successively in the Weston-super-Mare Electric Supply Company, and in the Birkdale and District Electric Supply Company. Afterwards he was appointed Engineer-in-Charge of the Westminster Electricity Supply Corporation, and in 1904 proceeded to Calcutta to take up the position of Electrical Engineer to the Ishapur Rolling Mills, which post he held until the time of his death. He was elected an Associate Member of the Institution in 1905.

PROFESSOR SAMUEL JOYCE died at Bombay on August 11, 1906, being at the time of his death 42 years of age. He was educated at High Barnet Grammer School, and on leaving school found employment at Messrs. Paterson & Cooper's Works, at Dalston, where, after two years' general training, he became Manager of the Instrument Department. He assisted in the design of some of the first electro-magnetic instruments, and later, brought out the dead-beat electro-magnet instruments bearing his name, which enabled the large currents then coming into use for electro-magnetic purposes to be measured with accuracy.

In 1891 he left Paterson & Cooper's to become lecturer in electrical engineering at the Whitworth Institute in Manchester, which soon after was merged in the Manchester Municipal Technical School. As a teacher he was eminently successful, and his lectures and practical classes were extremely popular. In 1897, feeling that he was losing touch with the practical world, he took a position as Manager of the Edison & Swan Company's Works at Broadheath, near Manchester, and Chief Engineer to the Altrincham Electric Supply Company. When the works at Broadheath were closed he was transferred to a position of increased responsibility at the Ponder's End Works of the Company. In 1902 he proceeded to Bombay to resume his work as lecturer, having been appointed to the Chair of Physics and Electrical Engineering at the Victoria Jubilee Technical Institute, a position which he filled until his death.

Professor Joyce was the author of a paper on "Electrical Measuring Instruments," for which he obtained the Miller Prize of the Students' Section of the Institution of Civil Engineers. Later, in Manchester, he published his book of "Examples in Electrical Engineering," which is widely used as a standard work by students and teachers. He also took an active part in the foundation of the Northern Society of Electrical Engineers, of which he was Secretary at the time of its

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fusion with the Institution of Electrical Engineers, and he acted as Hon. Secretary of the Manchester Local Section during the first year of its existence.

While in Bombay he founded, with two others, the *Indian Electrical, Mechanical and Textile News*, a monthly magazine devoted to the technical side of these subjects, which enjoys a prominent position among the technical papers of India. He had numerous interests outside his profession, among which were archæology and the ancient languages of the East. He became an Associate of the Institution in 1885, and a full Member in 1898.

JOHN WILLIAM LEYSHON died in November, 1906, at the age of 53. He was for nearly forty years in the service of the Post Office, the greater portion of which he spent in the Department of the Engineer-in-Chief. He acted as Engineer in the Glamorgan District, South Wales, and subsequently as Technical Officer at the General Post Office in charge of the survey of the London Post Office Telephone system. From 1894 to 1898 he lectured at the University College on telegraphy and telephony. He was elected an Associate of the Institution in 1894, and was transferred to the class of Members in 1902.

JOHN MACLEAN died in September, 1906. Born in 1875, he received his education at the Glasgow and West of Scotland Technical College and at the University of Glasgow, and his practical training as electrical engineer with Messrs. Mavor & Coulson, and Messrs. Anderson & Munro. Subsequently he went into business on his own account as Consulting Engineer. He was elected an Associate Member of the Institution in 1900.

THE RIGHT REV. MONSIGNOR GERALD MOLLOY, D.D., D.Sc., Rector of the University of Ireland, died suddenly at Aberdeen on October 1, 1906, in his 73rd year. He was educated at Castlenock College and Maynooth College, where he afterwards was Professor of Theology. In 1874 he was appointed Professor of Natural Philosophy at the University of Ireland. He achieved great popularity as a lecturer in experimental physics, and delivered numerous lectures on X-rays and wireless telegraphy at Dublin. He was elected a Member of the Institution in 1900, and served on the Committee of the Dublin Local Section in 1901.

RAJ SRI BOLLYCHAND PYNE died in January, 1907. For many years he was Assistant to the Electrician of the Indian Government Telegraph Department, and subsequently became Assistant Superintendent to the Department. At the time of his death he was in his 56th year. He was elected an Associate of the Institution in 1879, and was transferred to the class of Associated Members in 1899.

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CHARLES N. SIMS died in South Africa in July, 1906. He was educated at the Technical School, Cheltenham, and went through a course of training with the Lithanode and General Electric Company. Subsequently he was engaged as draughtsman by the Electricity Corporation of Cape Town, and in 1897 became Assistant Engineer in charge of the Testing Department of the Works. He was elected an Associate Member of the Institution in 1904.

ILLIUS AUGUSTUS TIMMIS died of pneumonia on December 13, 1906, on a voyage from America. Mr. Timmis's work on the application of electricity to railway signalling is well known. About 1883–5 he developed his system of electrically working railway signals, points, and block instruments, and in 1885 a paper was read by him before the Institution, in which Mr. Stanley Currie's and his own inventions in this connection were fully described. He also devised about the same time a system of lighting trains by electricity, and in conjunction therewith patented, jointly with Professor Forbes, a system of electric brakes for trains. Among other practical applications of his inventions the automatic signals on the Liverpool Overhead Railway are operated by the Timmis long-pull electro-magnets. Mr. Timmis was a Member of the Institution of Civil Engineers, and of the Institution of Mechanical Engineers, and was elected a Member of the Institution of Electrical Engineers in 1889.

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REFERENCES TO PAPERS READ BEFORE LOCAL SECTIONS OF THE INSTITUTION, AND PUBLISHED IN THE TECHNICAL PRESS, BUT NOT YET ORDERED TO BE PRINTED IN THE JOURNAL OF THE INSTITUTION.

BIRMINGHAM LOCAL SECTION.

"SOME CONSIDERATIONS INVOLVED IN THE DESIGN OF SWITCH GEAR FOR THE SUMMER LANE GENERATING STATION," BY J. E. WOODBRIDGE.

Electrical Engineering, Vol. **1**, p. 686, 1907.

DUBLIN LOCAL SECTION.

"THE EFFECT OF HIGH EFFICIENCY LAMPS ON THE ELECTRIC LIGHTING INDUSTRY," BY W. TATLOW, ASSOCIATE MEMBER.

Electrical Engineering, Vol. **1**, p. 588, 1907.
Electrician, Vol. **58**, p. 1005, 1907.

GLASGOW LOCAL SECTION.

"FUEL ECONOMY," BY H. B. MAXWELL, MEMBER.

Electrical Engineering, Vol. **1**, pp. 31, 100, 438, 1907.
Electrical Review, Vol. **60**, p. 245, 1907.
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"ILLUMINATION AND SOME ILLUMINANTS," BY J. D. MACKENZIE, ASSOCIATE.

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Electrical Review, Vol. **60**, p. 700, 1907.

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LEEDS LOCAL SECTION.

"PRACTICAL PHOTOMETRY AND ITS VALUE," BY H. T. HARRISON, MEMBER.

Electrical Engineer, Vol. **38**, p. 844, 1906.

"SUCTION GAS ENGINES AND GAS PLANTS," BY H. CAMPBELL, ASSOCIATE.

Electrical Engineering, Vol. **1**, p. 220, 1907.
Electrical Review, Vol. **60**, p. 325, 1907.
Electrician, Vol. **58**, p. 642, 1907.

"NOTES ON UNDERGROUND MAINS," BY W. M. ROGERSON, ASSOCIATE MEMBER.

Electrical Engineering, Vol. **1**, pp. 552, 791, 1907.
Electrical Review, Vol. **60**, p. 662, 1907.
Electrician, Vol. **58**, p. 965, 1907.

MANCHESTER LOCAL SECTION.

"CHEAPENED METHODS OF ELECTRICAL DISTRIBUTION," BY J. H. C. BROOKING, ASSOCIATE MEMBER.

Electrical Engineering, Vol. **1**, pp. 35, 629, 1907.
Electrical Review, Vol. **60**, p. 37, 1907.

"BREAKDOWNS OF ELECTRICAL MACHINERY," BY LL. FOSTER, MEMBER.

Electrical Engineer, Vol. **39**, p. 335, 1907.
Electrical Engineering, Vol. **1**, pp. 436, 460, 1907.
Electrical Review, Vol. **60**, p. 500, 1907.

NEWCASTLE LOCAL SECTION.

"THREE-PHASE ALTERNATING CURRENTS," BY J. S. BARNES, ASSOCIATE MEMBER.

Electrical Engineering, Vol. **38**, p. 889, 1906.

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NEWCASTLE LOCAL SECTION (continued)—

"POINTS IN POWER STATION DESIGN AND OPERATION," BY E. P. HOLLIS, STUDENT.

Electrical Engineer, Vol. **39**, pp. 109 and 111, 1907.
Electrical Engineering, Vol. **1**, p. 146, 1907.
Electrician, Vol. **58**, p. 593, 1907.

"THE INSULATION OF ELECTRICAL APPLIANCES," BY O. J. WILLIAMS, STUDENT.

Electrical Engineer, Vol. **39**, p. 549 1907.
Electrical Engineering, Vol. **1**, p. 3, 1907.
Electrician, Vol. **58**, p. 1007, 1907

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EXPLANATION OF ABBREVIATIONS.

[P] signifies a reference to the general title or subject of a Paper.

[*p*] signifies a reference to a subject incidentally introduced into a Paper.

[D] signifies a reference to remarks made in a Discussion upon a Paper, of which the general title or subject is quoted.

[*d*] signifies a reference to remarks incidentally introduced into a discussion on a Paper.

[*Ref*] signifies a reference to the place of publication in the technical press of a Paper read at a Local Section, and not yet printed in this Journal.

Note.—The lists of speakers in the Discussion upon any Paper will be found in the Table of Contents at the beginning of the volume.

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